AFFDL-TR-77-37

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AD A053588

DIGITAL SIMULATION OF FLEXIBLE AIRCRAFT RESPONSE TO SYMMETRICAL AND ASYMMETRICAL RUNWAY ROUGHNESS

Anthony G. Gerardi

Structural Integrity Branch
Structural Mechanics Division

August 1977

TECHNICAL REPORT AFFDL-TR-77-37

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Tony G. Gerardi

TONY G. GERARDI
Project Engineer

R.M. Bader

ROBERT M. BADER, Chief
Structural Integrity Branch
Structural Mechanics Division

FOR THE COMMANDER

Howard L. Farmer

HOWARD L. FARMER, COL, USAF
Chief, Structural Mechanics Division

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14

1. REPORT NUMBER: AFFDL-TR-77-37	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 DIGITAL SIMULATION OF FLEXIBLE AIRCRAFT RESPONSE TO SYMMETRICAL AND ASYMMETRICAL RUNWAY ROUGHNESS.	5. TYPE OF REPORT & PERIOD COVERED: 9 Final Technical Rep[redacted]t, Sep[redacted]75 - Aug [redacted]76,
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 [redacted] G./Gerardi Anthony	8. CONTRACT OR GRANT NUMBER(s) 17
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Flight Dynamics Laboratory, Structural Integrity Branch, Wright-Patterson AFB, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 01 Project No. 1367, Task No. 136701, Work Unit No. 13670113
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433	12. REPORT DATE: 11 Aug[redacted]77 12
	13. NUMBER OF PAGES: 83; 83 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Dynamics
Simulation
Ground Loads
Taxi Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method has been developed for determining the dynamic response of a flexible aircraft to runway roughness during takeoff or constant speed taxi. The equations that formulate the mathematical model have been programmed for a CDC 6600 digital computer and uses a Calcomp plotter for part of the program output. Three sets of runway elevation data are input to provide a forcing function at each landing gear. Three runway profiles measured at Washington National Airport, runway 36, were used to represent a typical commercial

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asymmetric profile. Three lines of profile were analytically generated to represent traversing a 1-cos dip at a 45 degree angle of approach.

Several aircraft have been simulated with this program, each during a takeoff and a constant speed taxi. The data used to simulate the airplanes (McDonnell Douglas C-9A, Boeing 727-100, and an AMST) and the runway profile data used, are included in the appendix of this paper.

Comparison of simulated results to limited experimental data was good. Peak vertical acceleration levels at the pilot's station were within 14%.

The effect of the asymmetry of a profile on pilot's station vertical acceleration was significant providing the asymmetry of the profile was significant.

FOREWORD

This report was prepared by A. G Gerardi, Aerospace Engineer in the Loads and Response Prediction Group of the Structural Mechanics Division of the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Ohio. The work described herein is a part of the Air Force Systems Command exploratory development program to predict aircraft dynamic loads during ground operations. The work was directed under Project 1367, "Structural Integrity for Military Aerospace Vehicles," Task 136701, "Structural Flight Loads Data."

This report covers work done in the period from September 1975 to August 1976.

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SECTION I
INTRODUCTION

A common problem that can occur during takeoff and taxiing operations of aircraft is high acceleration levels caused by a rough runway. Due to these accelerations, runways must be evaluated with respect to roughness in order to ensure timely pavement maintenance to control aircraft structural loads and fatigue. Also, rough runways adversely affect the ability of the crew members by reducing instrument readability and crew comfort. Figure 1 shows the current criterion (Reference 1) used to set maximum allowable vertical acceleration levels from a human comfort standpoint. Reference 2 addressed the runway roughness problem at considerable length and contains the development of a mathematical model and subsequent computer program called "TAXI" to simulate the dynamic response of military aircraft to runway roughness on a symmetrical runway. For a symmetric runway, only one runway profile is required. Normally this is sufficient for representing a paved runway. With the advent of the AMST (Advanced Medium STOL Transport) and is some cases with conventional airplanes operating off of semiprepared or very rough paved surfaces, the rolling motion of an aircraft became significant. This rolling motion was the result of operating the aircraft on an asymmetric runway. Therefore, in order to properly simulate this response it became necessary to include the runway profile encountered by each landing gear.

1. PURPOSE OF THIS STUDY

The purpose of this study is to develop a computer program, capable of simulating an aircraft during constant speed taxi or takeoff from runways that are asymmetrical.

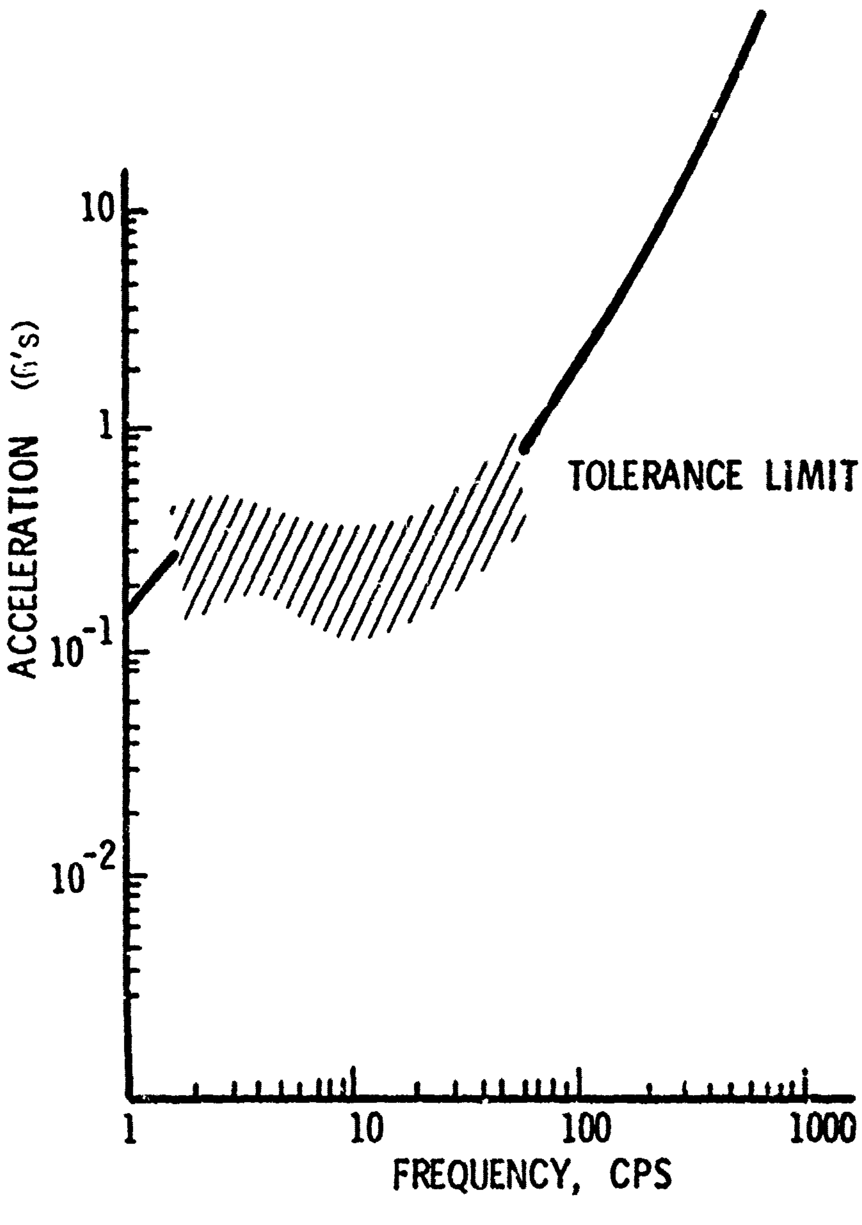

Figure 1. Accepted Military Human Tolerance Vertical Vibration Criterion

SECTION II
MATHEMATICAL MODEL

The airplane/runway mathematical model used for this study was the basic mathematical model developed in Reference 2. A detailed description of the components that make up this general model, as well as the assumptions made are shown in Reference 2. This report presents, in summary form, the landing gear strut and tire representation, the airplane rigid body and flexible body representation, the runway profile representation, the equations of motion, and the solution technique.

1. GENERAL AIRPLANE/RUNWAY MODEL

The general model represents an asymmetrical body with a nose gear and a right and left main landing gear. Each landing gear strut is assumed to have point contact with the profile and it is assumed that each landing gear traverses a different profile. Aerodynamic lift and drag are modeled, and thrust is applied at the aircraft's center of gravity.

The airplane is free to roll, pitch, plunge, and translate horizontally down the runway and each landing gear unsprung mass is free to translate vertically. To these rigid body degrees of freedom, up to 30 flexible modes of vibration are included. This airplane motion is controlled by the landing gear strut forces, lift, drag, thrust, and the resisting parameters of aircraft mass and inertia.

The landing gear struts are nonlinear, single acting oleo pneumatic energy absorbing devices (Figure 2) and are represented in the model as the sum of the three forces; pneumatic, hydraulic, and strut bearing friction forces. The pneumatic force, which is the largest of the three is represented by the equation:

$$F_A = \frac{PV}{\frac{V}{A} - S} \tag{1}$$

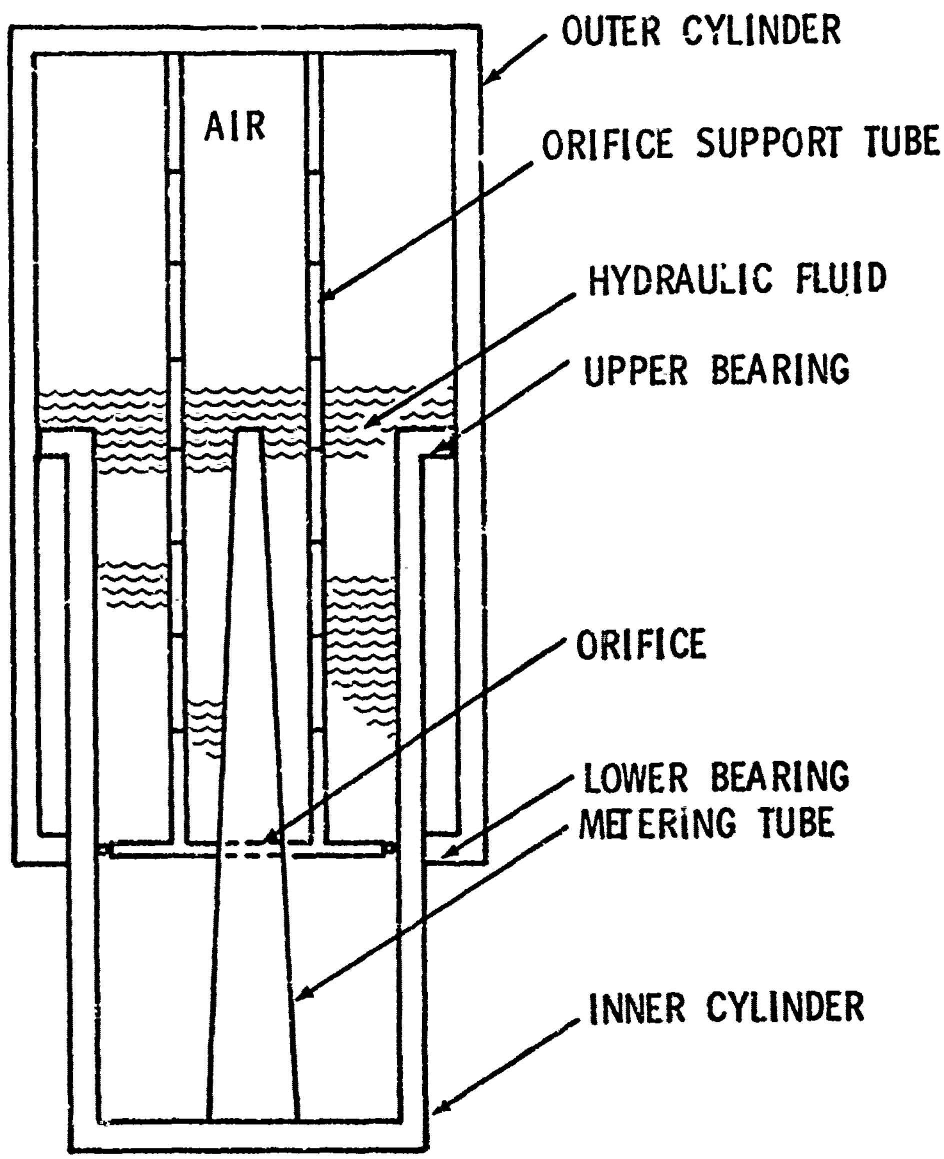

Figure 2. Typical Single Acting Oleo Pneumatic Landing Gear Strut

where:

P = fully extended strut pressure

V = fully extended strut volume

A = pneumatic piston area

S = strut stroke

The damping force is given by the equation:

$$F_h = \frac{\rho_h A_h^3 \dot{S}| \dot{S}|}{2 (C_d A_o)^2} \quad (2)$$

where:

ρ_h = density of the hydraulic fluid

A_h = the hydraulic piston area

A_o = effective orifice area (constant orifice minus metering pin area)

C_d = orifice coefficient (use 0.9)

$\dot{S}$ = strut piston velocity

The third strut force is the strut bearing friction force and is neglected in the model because the force is small for symmetrically loaded struts. (See Reference 2).

The tire force is represented by the linear equation:

$$F_T = k T_D \quad (3)$$

where:

T_D = tire deflection

k = linear tire spring constant

The runway elevation data is input into the model in two foot increments. The profile is made continuous by fitting the following polynominal through the three elevation data points and the slope at the end of the previous profile segment:

$$y(x) = a_1 + a_2x + a_3x^2 + a_4x^3 \tag{4}$$

where:

$a_{1,2,3,4}$ = coefficients derived from the elevation and slope data

This is done for each of the three lines of runway profile data.

2. RIGID BODY EQUATIONS OF MOTION

The differential equations of motion for the mathematical model were derived by application of the Lagrange equations (See Appendix A). The general form of these equations is shown below and corresponds to the notation shown in Figure A-1 in Appendix A.

$\ddot{Z} = (F_{s1_*} + F_{s2} + F_{s3} + L - W)/M_{cg}$ [c.g., vertical acceleration] (5)

$\ddot{Z}_1 = (F_{t1} - F_{s1} - W_1)/M_1$ [unsprung mass vertical acceleration] (6)

$\ddot{Z}_2 = (F_{t2} - F_{s2} - W_2)/M_2$ [unsprung mass vertical acceleration] (7)

$\ddot{Z}_3 = (F_{t3} - F_{s3} - W_3)/M_3$ [unsprung mass vertical acceleration] (8)

$\ddot{\theta} = (F_{s1}A + F_{s2}B + F_{TD}\epsilon_1 - F_{s3}C)/I_{yy}$ [pitching acceleration] (9)

$\ddot{\phi} = (F_{s3} - F_{s2})C/I_{xx}$ [rolling acceleration] (10)

$\ddot{X} = (F_T - F_{TD} - F_{AD})/(M_{cg})$ [horizontal translation acceleration] (11)

where:

F_{s1}, F_{s2}, F_{s3} = total landing gear strut forces

F_{t1}, F_{t2}, F_{t3} = tire forces

M_{cg}, W, I_{yy}, I_{xx} = aircraft mass, weight, and pitching and roll inertias

*The subscript 1, 2 and 3 corresponds to the nose, right main and left main landing gears respectively.

W_1, W_2, W_3 = upsprung landing gear weights

A, B, C, ε_1 = moment arms

L, F_T, F_{TD}, F_{AD} = lift, thrust, and tire and aerodynamic drag forces [F_T and F_{AD} act through the center of gravity]

3. FLEXIBILITY EQUATIONS OF MOTION

$$M_i\ddot{q}_i = \xi_{i1}F_{s1} + \xi_{i2}F_{s2} + \xi_{i3}F_{s3} - 2\zeta_i\omega_i\dot{q}_i - \omega_i^2 M_i q_i \text{ for the ith mode}$$

where:

M_i = the generalized mass

ξ_{i1}, ξ_{i2}, ξ_{i3} = modal deflections at gear location 1, 2 and 3

ω_i = modal frequency

ζ = damping factor

$q_i = \dot{q}_i$, $\ddot{q}_i$ = generalized coordinates and their time derivatives.

The sign convention is as follows:

Z = Vertical Displacement	+ up
θ = Pitch	+ nose down
φ = Roll	+ roll right
q = Deflection Due to Bending	+ up
X = Horizontal Translation	+ forward

4. SOLUTION TECHNIQUE

The technique used for solving the coupled nonlinear differential equations of motion that describe the simulated aircraft is a three-term Taylor series. For example, the equation:

$$\ddot{x} = -c\dot{x} - kx \tag{12}$$

The three term Taylor series representations can be written as

$$X_{(I+1)} = X_{(I)} + \dot{X}_{(I)}(\Delta t) + \ddot{X}_{(I)}\frac{(\Delta t)^2}{2} \tag{13}$$

where: $I = 1 \rightarrow N$

The values for $\ddot{x}$, $\dot{x}$ and x from the previous step are substituted into Equation 13 and a new value for x is obtained. Differentiating Equation 13 we obtain for the velocity $\dot{x}$, the expression:

$$\dot{x}_{(I+1)} = \dot{x}_{(I)} + \ddot{x}_{(I)} (\Delta t) \tag{14}$$

The values for $\dot{x}$ and $\ddot{x}$ are then substituted into Equation 14 and a new value of $\dot{x}$ is found. This entire process is repeated with the new values of x and $\dot{x}$ to obtain the next point in the solution.

SECTION III
COMPUTER PROGRAM

The computer program, TAX2, which computes the dynamic response of a flexible aircraft to an asymmetrical runway profile, consists of one basic program and several subroutines. A complete listing of the program is contained in Appendix B. Table 1 contains a description of the aircraft input data and Figure 3 shows the source deck setup for use on the CDC 6600 computer at Wright-Patterson AFB, Ohio.

1. OUTPUT FORMAT

The results of the calculations are presented as both a printed output and a time history plot. The printed output lists the value of fifteen parameters each 0.01 second. A sample of this listed output is shown in Table 2. The fifteen parameters listed in the heading are:

XMAINL	-	Left Main landing gear strut deflection (inches)
XMAINR	-	Right Main landing gear strut deflection (inches)
XNOSE	-	Nose gear strut deflection (inches)
ZPML	-	Left Main landing gear runway elevation (inches)
ZPMR	-	Right Main landing gear runway elevation (inches)
ZPN	-	Nose landing gear runway elevation (inches)
BETADD	-	Rolling acceleration ($\ddot{\phi}$) (rad/sec^2)
THETADD	-	Pitching acceleration ($\ddot{\Theta}$) (rad/sec^2)
BETA	-	Roll angle (ϕ) (rad)
THETA	-	Pitch angle (Θ) (rad)
SPEED	-	Aircraft velocity (ft/sec)
DISTANCE	-	Distance traveled down the runway (feet)
TIME	-	Real time (seconds)
CGACC	-	Center of Gravity Vertical Acceleration (g's)
PSA	-	Pilot's Station Vertical Acceleration (g's)

Figure 4 shows a photographic reduction of a typical Calcomp-plotted time history. This figure depicts a Boeing 727-100 taxiing at 50 fps over a 1-cos bump at a 45° angle of approach. The plotted output includes titles showing the airplane simulated, its gross weight,

TABLE 1

DESCRIPTION OF INPUT AIRCRAFT DATA

Section 1 (cards 1-5) - General Airplane Data

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
Card 1				
1-80	8A10	PLANE	McDonnell-Douglas C-9A	Airplane Being Simulated and Gross Weight
Card 2				
1-10	F10.1	W	108000.	Vehicle Weight (lbs)
11-20	F10.1	A	51.6	Distance Main Gear to CG (in)
21-30	F10.1	B	589.4	Distance Nose Gear to CG (in)
31-40	F10.1	MMI	20800000.	Pitch Moment of Inertia (lb in sec^2)
41-52	F12.0	WS	96.	Wing Station of Main Gear (in)
53-64	F12.0	MMIR	8000000.	Roll Moment of Inertia (lb in sec^2)
Card 3				
1-10	F10.2	PSARM	607.0	Distance of Pilot Station to CG (in)
11-20	F10.2	TAILRM	318.5	Distance of Tail Station to CG (in)
Card 4				
1-10	F10.2	SPEED	50.	Initial Velocity of Airplane (ft/sec)
11-20	F10.2	THRUST	29000.	Total Airplane Thrust (lbs)
21-30	F10.2	TAKEOFF	285.5	Airplane Rotation Speed (ft/sec)

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
Card 5				
1-10	F10.4	CL	1.1	Lift Coefficient
11-20	F10.4	AREA	1000.7	Wing Area (ft^2)
21-30	F10.4	CD	.1	Drag Coefficient
Section 2 (cards 6-11) - Main and Nose Gear				
Card 6				
1-10	F10.2	WM	957.16	Unsprung Weight of Each Main Gear (lbs)
11-20	F10.2	WN	153.43	Unsprung Weight of Nose Gear (lbs)
21-30	F10.2	SXM	2.	Number of Main Gear Struts
31-40	F10.2	SXN	1.	Number of Nose Gear Struts
Card 7				
1-10	F10.5	AHN	6.745	Hydraulic Piston Area Nose (in^2)
11-20	F10.5	AAN	8.2958	Pneumatic Piston Area Nose (in^2)
21-30	F10.5	AHM	16.5	Hydraulic Piston Area Main (in^2)
31-40	F10.5	AAM	21.648	Pneumatic Piston Area Main (in^2)
Card 8				
1-10	F10.5	PAOH	120.	Nose Strut Preload Pressure (lbs/in^2)
11-20	F10.5	PAOM	220.	Main Strut Preload Pressure (lbs/in^2)

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
21-30	F10.5	VON	126.2	Fully Extended Nose Strut Air Volume (in^3)
31-40	F10.5	VOM	366.0	Fully Extended Main Strut Air Volume (in^3)
41-50	F10.5	OAM	.543	Orifice Area Main (in^2)
51-60	F10.5	OAN	.442	Orifice Area Nose (in^2)
Card 9				
1-10	F10.3	SLM	85.5	Distance from Axle to CG Waterline Main Gear Strut Unloaded (in)
11-20	F10.3	SLN	87.3	Distance from Axle to CG Waterline Nose Gear Strut Unloaded (in)
Card 10				
1-10	F10.1	TSM	23428.6	Main Tire Spring Constant Per Strut (lbs/in)
11-20	F10.1	TSN	8632.5	Nose Tire Spring Constant Per Strut (lbs/in)
Card 11				
1-10	F10.5	DX	.001	Integration Step Size
Card 12				
1-5	I5	IFPLOT	0	0-Plot; 1-No Plot
6-10	I5	IFLIST	0	0-List; 1-No List
Section 3 (cards 13-16) - Metering Pin Description				
Card 13				
1-5	I5	NSCN	5	Number of Slope Changes Nose Gear

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
* Card 14A, 14B,....				
1-10	F10.3	STROKN (I)	*	Stroke Corresponding to Metering Pin Diameter, Nose Gear
11-20	F10.3	PINDN (I)	*	Metering Pin Diameter, Nose Gear (in)
Card 15				
1-5	I5	NSCM	*	Number of Slope Changes Main Gear
* Card 16A, 16B,....				
1-10	F10.3	STROKM (I)	*	Stroke Corresponding to Metering Pin Diameter, Nose Gear
11-20	F10.3	PINDM (I)	*	Metering Pin Diameter, Main Gear (in)
Section 4 (cards 17-19) - Flexibility Data				
Card 17				
1-5	I5	NFM	7	Number of Symmetrical Flexible Modes
6-10	I5	NAFM	7	Number of Asymmetrical Modes
** Card 18A, 18B,....				
1-10	F10.3	SIMAIN (I)	**	Mode Shape Deflection Main Gear
11-20	F10.3	SINOSE (I)	**	Mode Shape Deflection Nose Gear
21-30	F10.3	SICG (I)	**	Mode Shape Deflection CG
31-40	F10.3	SITAIL (I)	**	Mode Shape Deflection Tail Station

TABLE 1 (Continued)

Card Column	Format	Variable Name	Data for McDonnell-Douglas C-9A	Definition
41-50	F10.3	SIPS	**	Mode Shape Deflection Pilot Station
** Card 19A, 19B,....				
1-15	F15.2	GM (I)	**	Generalized Mass (lbs sec^2/in)
16-25	F10.3	OMEGA (I)	**	Modal Frequency (rad/sec)
** Card 20A, 20B,....				
1-10	F10.3	SILEFT (I)	**	Deflection for Left Main Gear
11-20	F10.3	SIRIGHT (I)	**	Deflection for Right Main Gear
** Card 21A, 21AB,....				
1-15	F15.3	GMA (I)	**	Asymmetrical Generalized Mass (lbs sec^2/in)
16-25	F10.4	OMEGAA (I)	**	Asymmetrical Modal Frequency (rad/sec)

* One card is required for each stroke-metering pin combination read into the program.

** One card is required for each flexible mode.

Note: A summary of all the data used in this study is shown in Appendix C.

TABLE 1 (Concluded)

Runway Profile Magnetic Tape

The runway profile is read into the program from a magnetic tape or permanent file. The format for this is shown below:

Column	Format	Variable Name	Definition
Read 1			
1-80	8A10	SITE**	Runway Profile and Direction
Read 2			
1-6	I6	NPTSS**	Number of Runway Elevation Points
* Read 3, 4,....N+2			
1-70	10F7.3	ELEVL**	Runway Profile Data
		ELEV	
		ELEVR	

* One read required for every ten runway profile elevation points.

** The process is repeated for each of the three profiles.

Note: All of the runway profile data used in this study is listed in Appendix D.

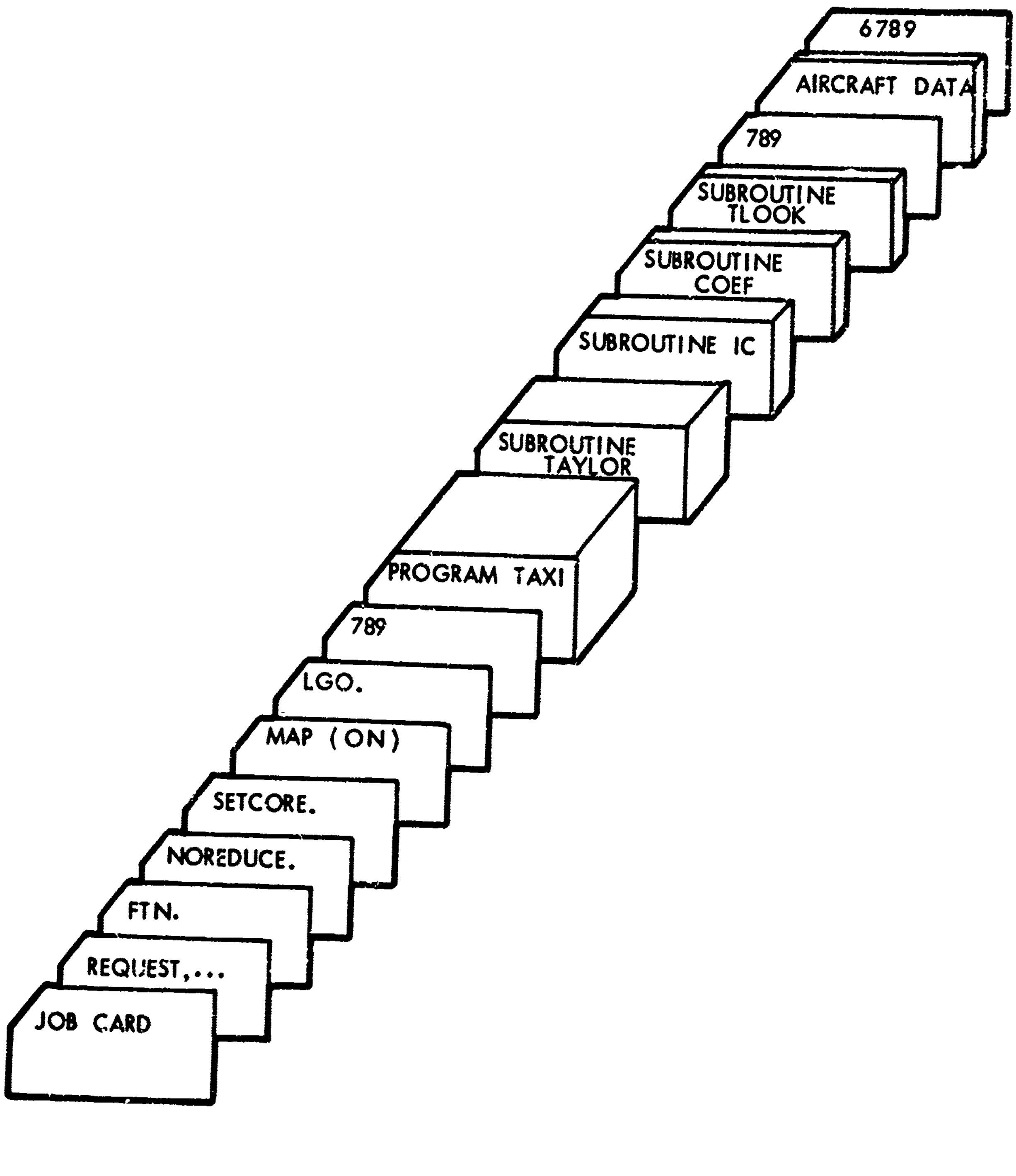

Figure 3. Source Deck Setup

TABLE 2

TYPICAL COMPUTER OUTPUT LISTING

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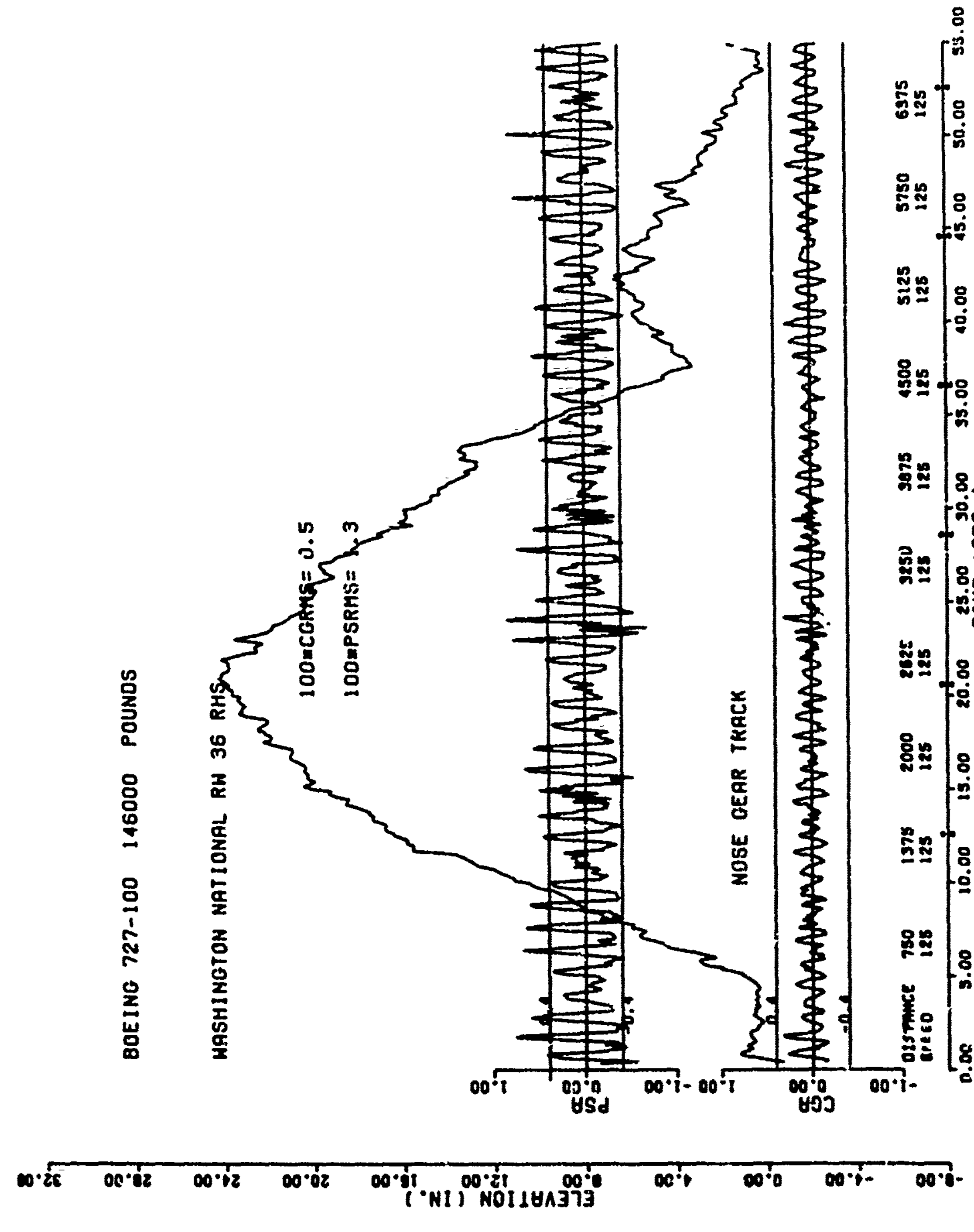

Figure 4. Typical Calcomp Plotted Output

the runway number and its location. The abscissa is the time axis annotated every second. At every time annotation the current value of aircraft speed, in feet per second, and the current aircraft position on the runway, in feet, are printed out. Runway markers (1,000-foot markers) are also plotted on the time scale to aid in aircraft positioning. The plot titled "Nose Gear Track" is a time history of the runway profile as it is encountered by the aircraft's nose gear. The actual runway profile is preceded by 100 feet of smooth surface to allow any starting transients to damp out prior to encountering the actual profile. There are two aircraft acceleration time histories that are of particular interest. One is the vertical acceleration at the pilot's station (PSA), the other is the vertical acceleration at the aircraft's center of gravity (CGA). Each time history is banded by the human tolerance criterion of ± 0.4 g. In order to minimize the amount of computer central memory required to store the acceleration time histories, the higher frequency components were effectively filtered out by limiting the sampling interval. All of the acceleration peaks, however, are shown on the plot. It should be noted that the pilot station acceleration time history is not always within the band of accepted human tolerance criteria. Thus, the plot is very useful in that it provides a graphical record of the level of acceleration, and it shows which bumps in the runway profile caused the high acceleration response.

SECTION IV
DISCUSSION OF SIMULATIONS

Table 3 contains a summary of the simulations made in this study. Three different airplanes were simulated: the Boeing 727-100, the McDonnell Douglas C-9A, and an AMST configuration. Each airplane was simulated traversing two profiles: Washington National Runway 36, and a 1-cos dip. Simulations were made using mathematical models with and without a roll degree of freedom, i.e. one or three profiles, and with and without flexible wings so that comparisons of the responses could be made.

Figures 5 and 6 show the plotted results of a Boeing 727-100 traversing the Washington National runway profile without a roll degree of freedom and with a roll degree of freedom respectively. Both runs were made at a constant speed of 125 feet per second, because this speed produced higher levels of vertical acceleration for this airplane. Comparison of these two figures shows a significant increase in the vertical acceleration at the pilot's station (P.S.) while the aircraft is at different locations on the runway. For example, at T=46 sec. P.S. acceleration levels more than doubled when three lines of profile were used. This is attributed to the fact that the profiles seen by the main landing gear were rougher in the latter case. Figure 7 shows the Power Spectral Density (PSD) levels of each line of survey for the Washington National runway. A PSD is a measure of the relative roughness of a runway versus frequency. It can be seen that the PSD level is different for each line of survey which accounts for the change in the aircraft's dynamic response. Figures 8 and 9 show the 727-100 traversing a 1-cos dip headon and at a 45° angle respectively. In this case the speed was 50 fps which "tunes" the natural pitching frequency (1 cps) of the 727-100 to this 1-cos dip. Hitting the 1-cos dip at an angle caused an increase in the peak P.S. and C.G. acceleration levels.

In was necessary to try to simulate different aircraft with the computer program in an effort to check the program's versatility.

TABLE 3

SUMMARY OF SIMULATIONS

Run #	Airplane	Profile	Speed	Remarks
1	727-100	Washington National (C)	125 fps	No Roll DOF*, Rigid Wings
2	727-100	Washington National (L,C,R)	125 fps	With Roll DOF, Rigid Wings
3	727-100	(1-cos) (C)	50 fps	No Roll DOF, Rigid Wings
4	727-100	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
5	C-9A	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
6	AMST	(1-cos) (L,C,R)	50 fps	With Roll DOF, Rigid Wings
7	727-100	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
8	AMST	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
9	C-9A	Washington National (L,C,R)	Takeoff	With Roll DOF, Rigid Wings
10	C-9A	(1-cos) (L,C,R)	50 fps	With Roll DOF, Flexible Wings
11	C-9A	Washington National (L,C,R)	Takeoff	With Roll DOF, Flexible Wings

* Degree of Freedom

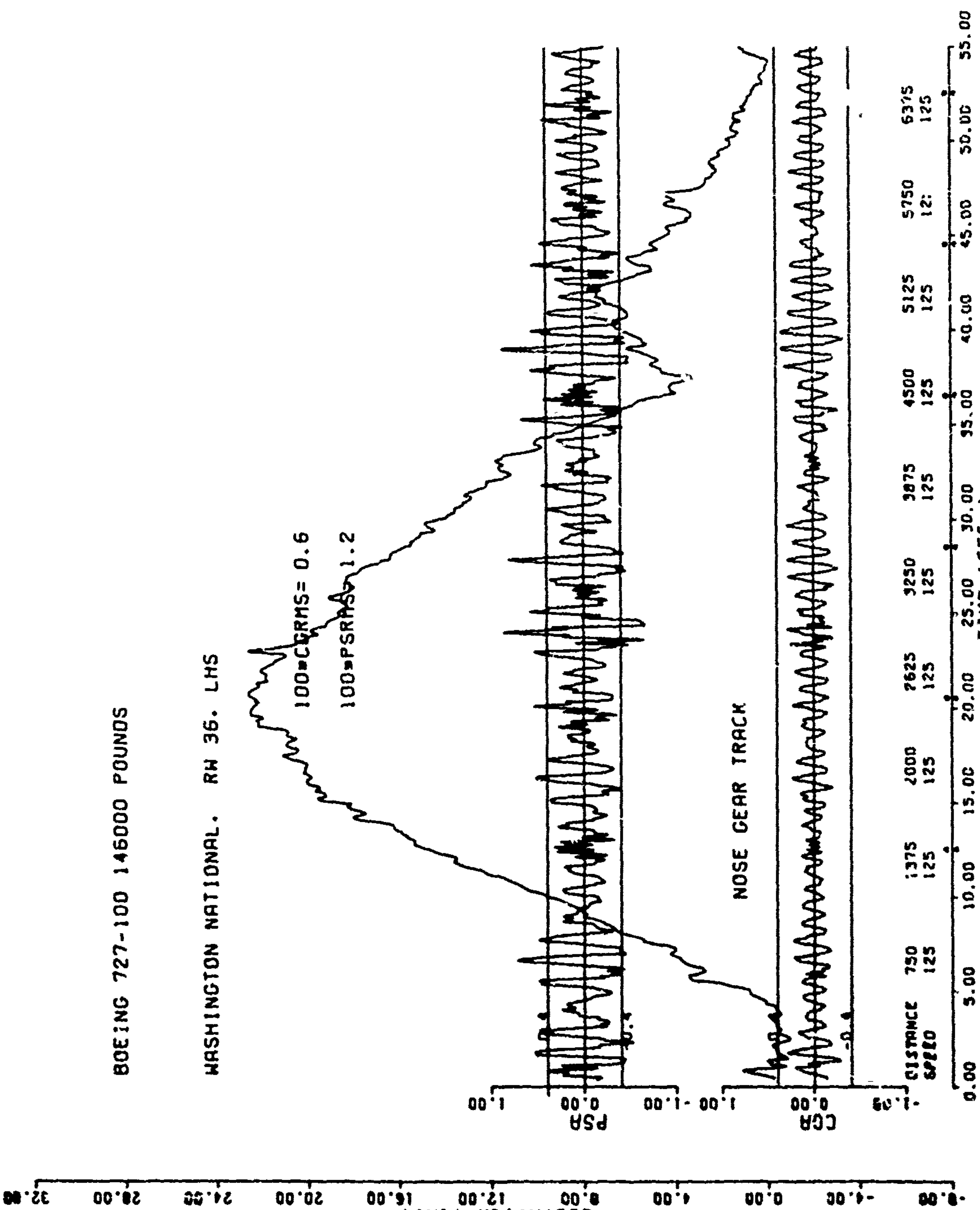

Figure 5. Boeing 727-100 Constant Speed Taxi Simulation over the Washington National Profile Without a Roll Degree of Freedom

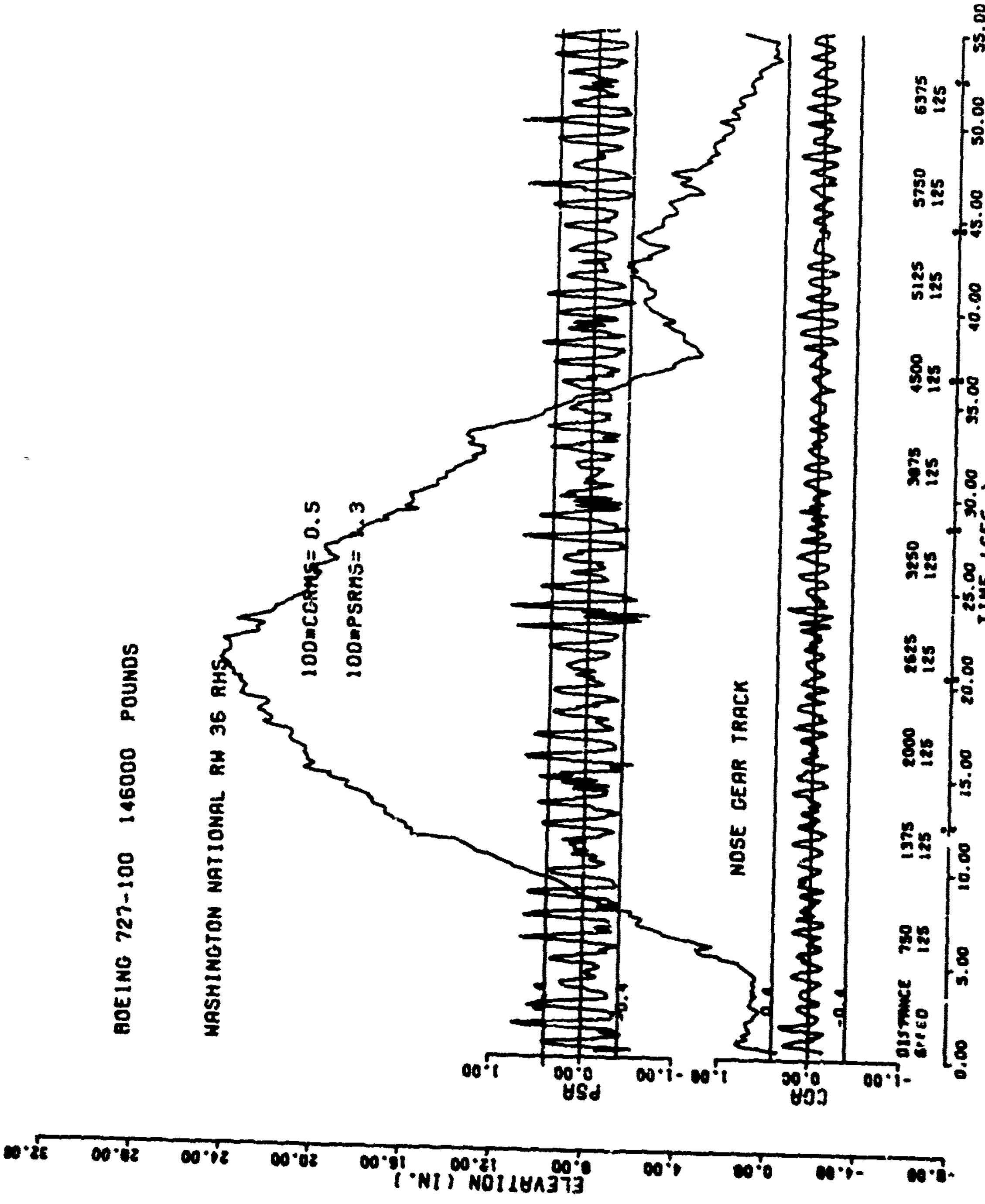

Figure 6. Boeing 727-100 Constant Speed Taxi Simulation over the Washington National Profile With a Roll Degree of Freedom

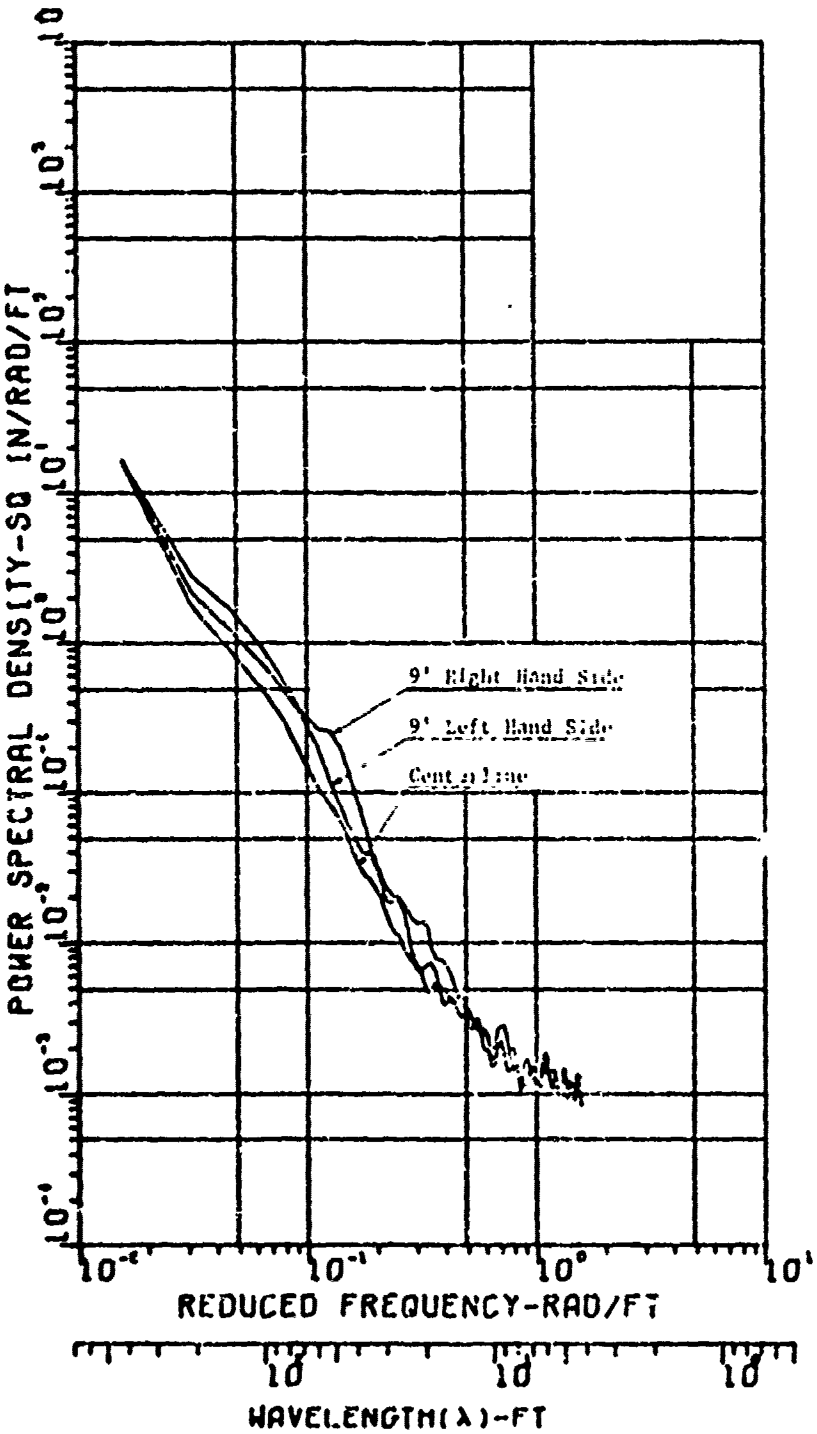

Figure 7. PSD of Washington National Airport Runway 36

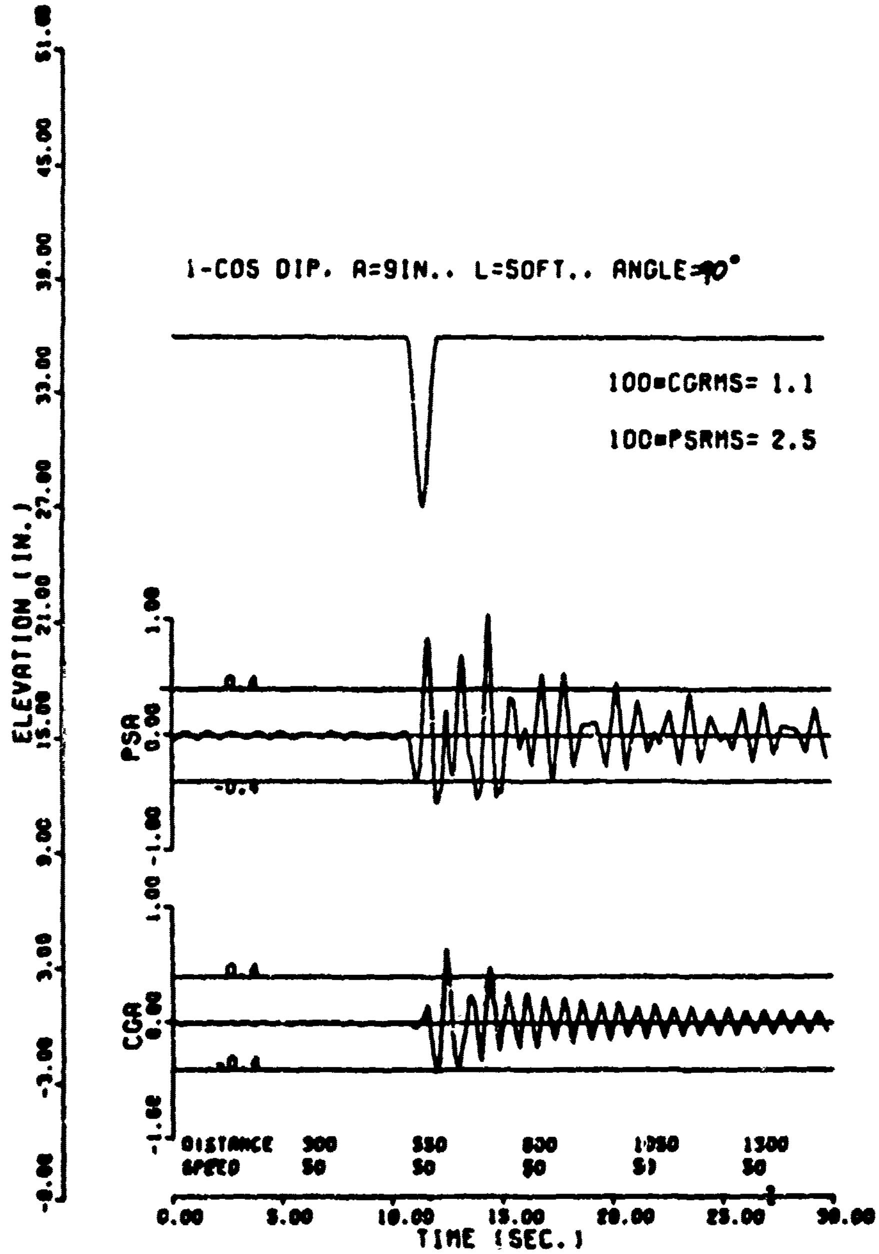

Figure 8. Boeing 727-100 Traversing a (1-cos) dip head-on.

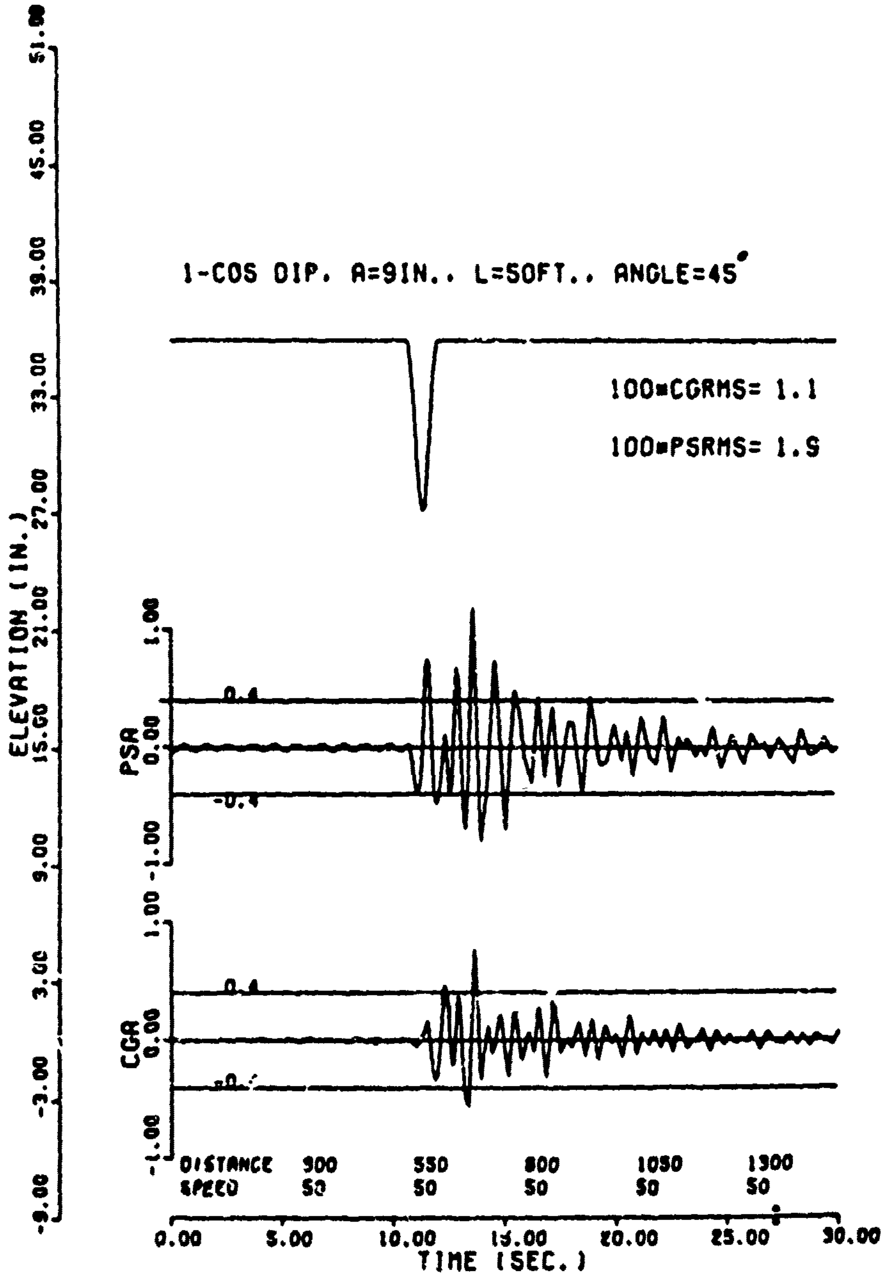

Figure 9. Boeing 727-100 Traversing a (1-cos) dip at a 45° angle

Figures 10 and 11 show the plotted results of the C-9A and AMST respectively hitting the 1-cos dip at a 45° angle at a constant speed of 50 fps. While the C-9A had a relatively high response, the AMST, which is designed to operate off of rough fields, "absorbed" the dip to a large degree. This indicates that the computer program is calculating relative responses which are at least intuitively correct.

Up to this point only constant speed simulations have been discussed. Figures 12, 13 and 14 show the plotted results of the Boeing 727-100, AMST and the C-9A respectively taking off from the Washington National runway profile. Takeoff simulations are made by starting at a near zero forward velocity and accelerating at a constant thrust until rotation speed is reached, then the simulation is terminated. Again it can be seen that the AMST (which is designed for rough field operation) had a very low dynamic response, even though this runway is relatively rough. Figure 15 shows the plotted PSD's of Washington National Runway 36 and of two typically smooth runways, one at Portland Oregon and one at Dulles International. The Washington National Runway is significantly rougher.

Experimental data was available for comparison with the 727-100 takeoff simulation. Figure 16 shows the actual time history plots of vertical acceleration measured on a 727-100 taking off at 120,000 pounds gross weight from Washington National Runway 36 on December 11, 1972. Some parameters of the test aircraft were unknown such as strut and tire pressures and actual inertias. So exact simulation was not possible. However, Table 4 shows that comparison of several peak values of vertical accelerations at the P.S. were within 15 percent. The comparisons of C.G. vertical accelerations were not as good. In the simulation the acceleration levels were lower. It appears that main gear strut pressures on the actual airplane were lower than that simulated. This difference would cause the higher response in the plunge mode.

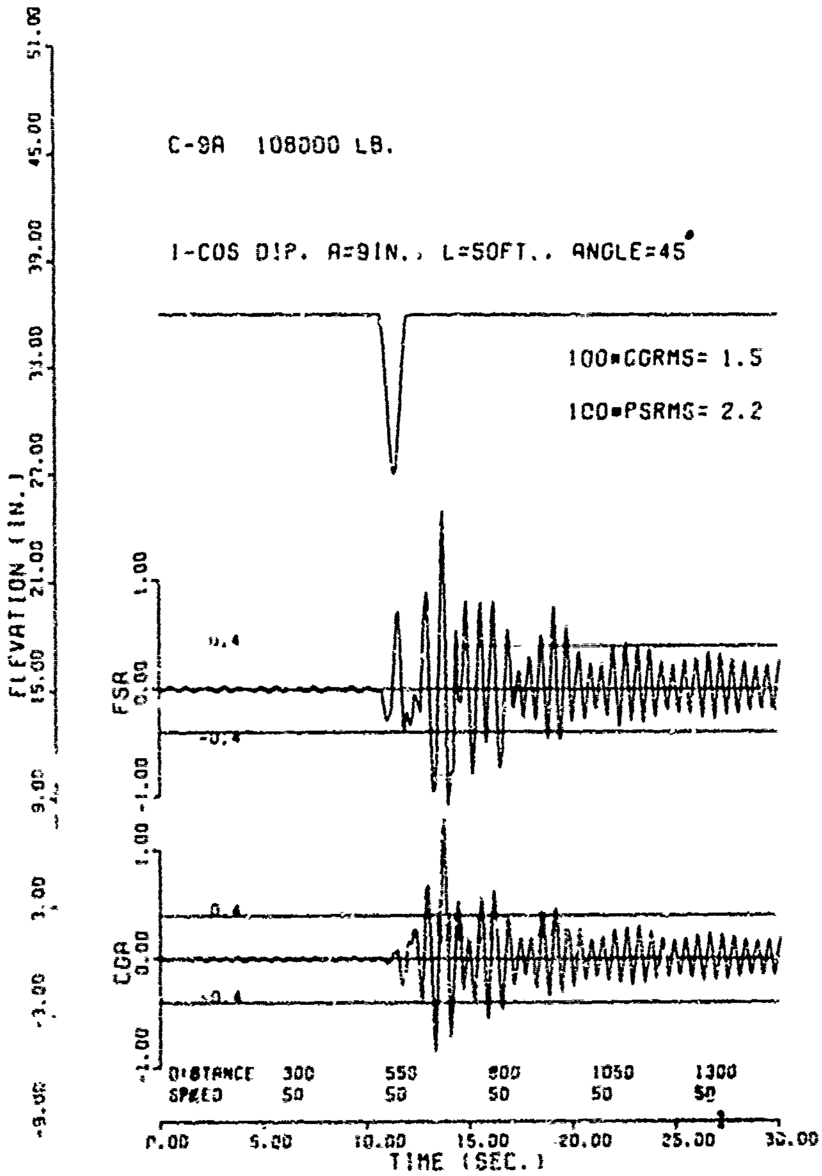

Figure 10. C-9A Traversing a (1-cos) dip at a 45° angle

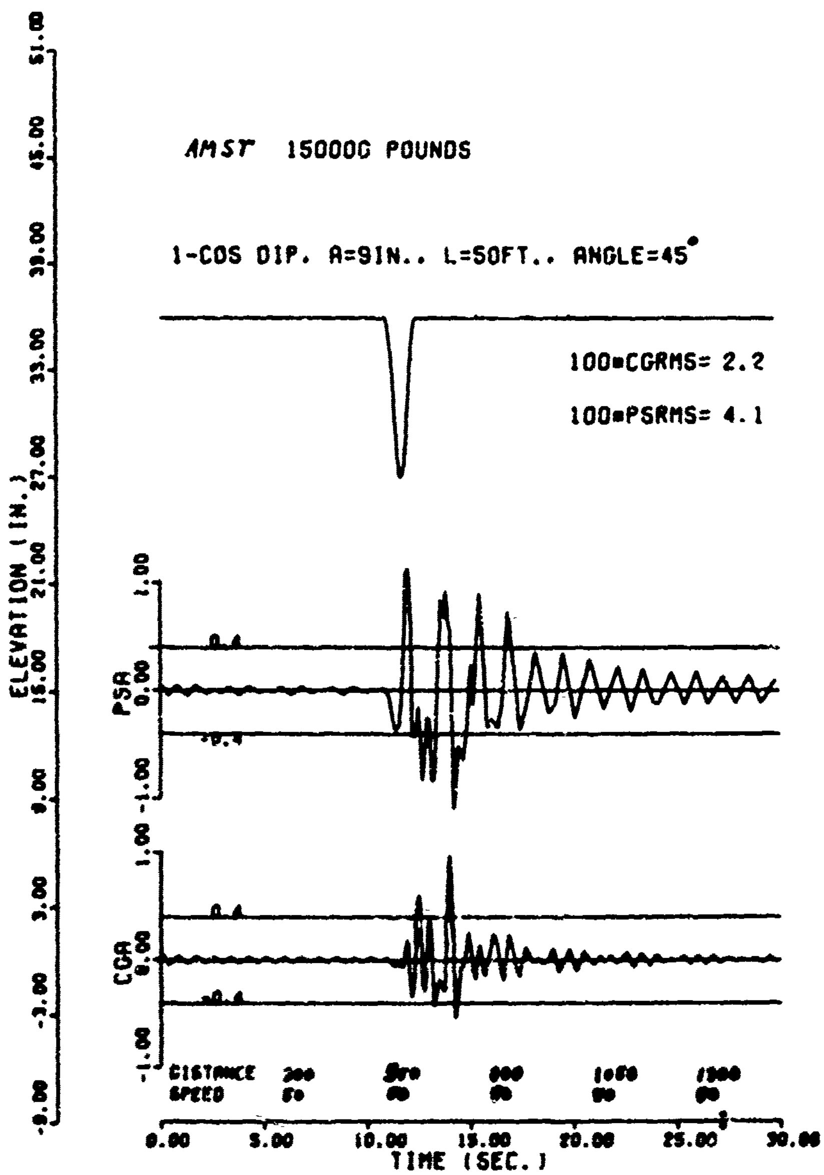

Figure 11. AMST Traversing a (1-cos) dip at a 45° angle

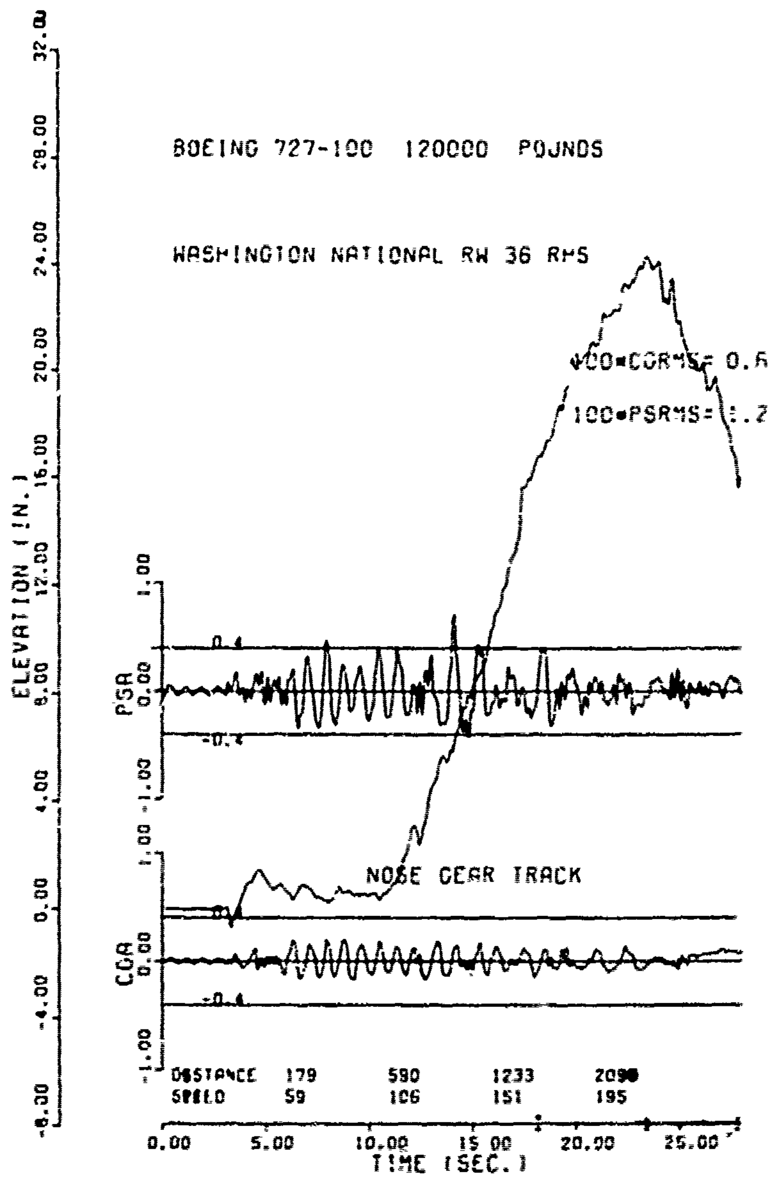

Figure 12. Boeing 727-100 Taking Off from Washington National Airport With the Roll Degree of Freedom Included

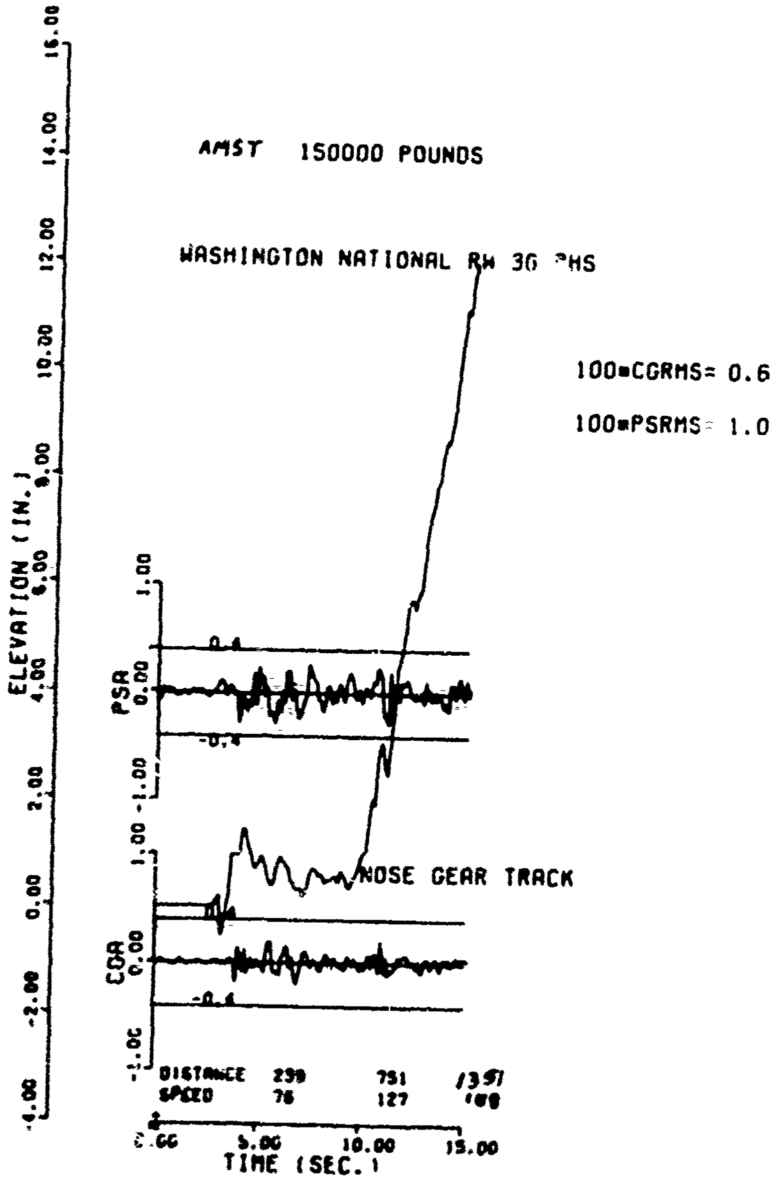

Figure 13. AMST Taking Off from Washington National Airport With the Roll Degree of Freedom Included

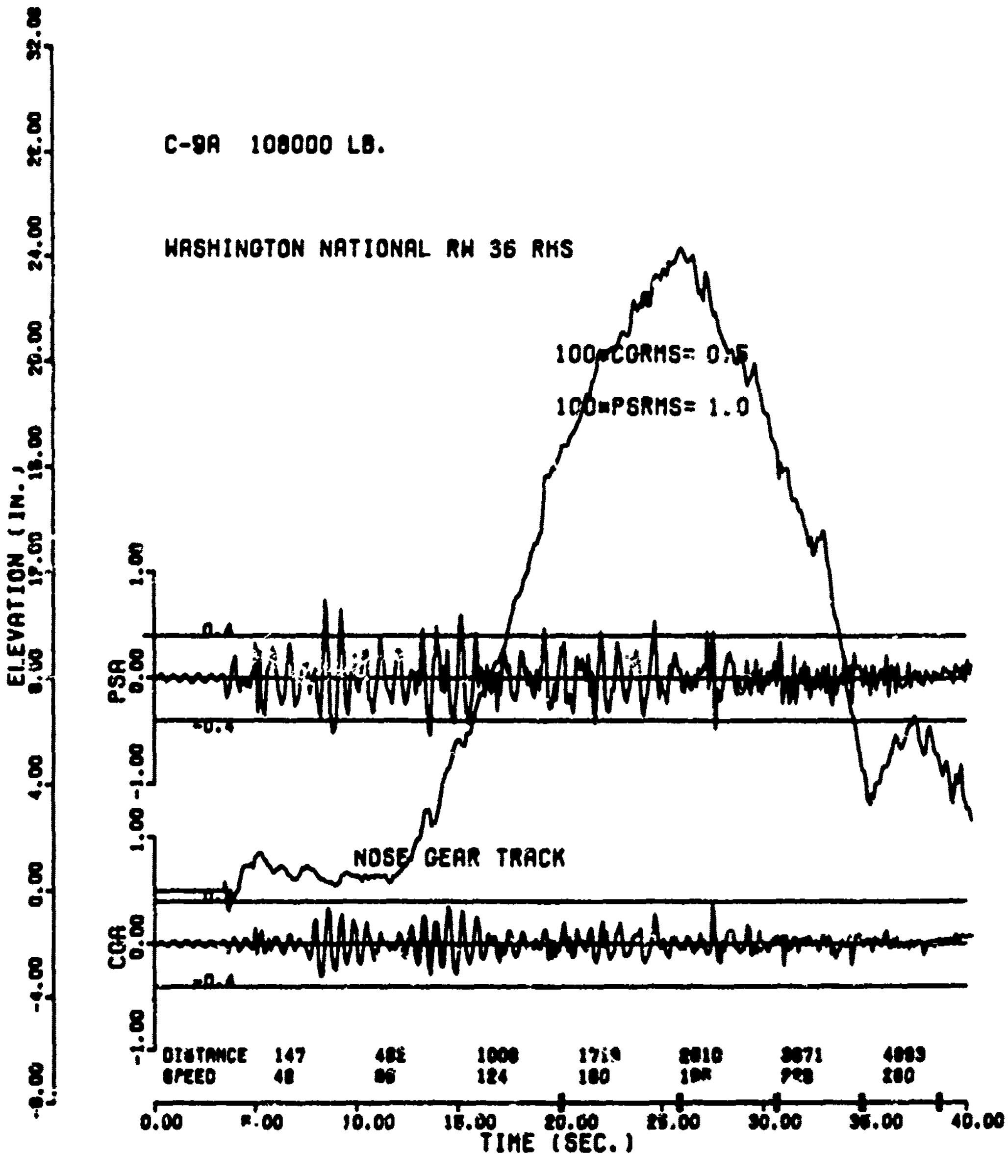

Figure 14. C-9A Taking Off from Washington National Airport With the Roll Degree of Freedom Included

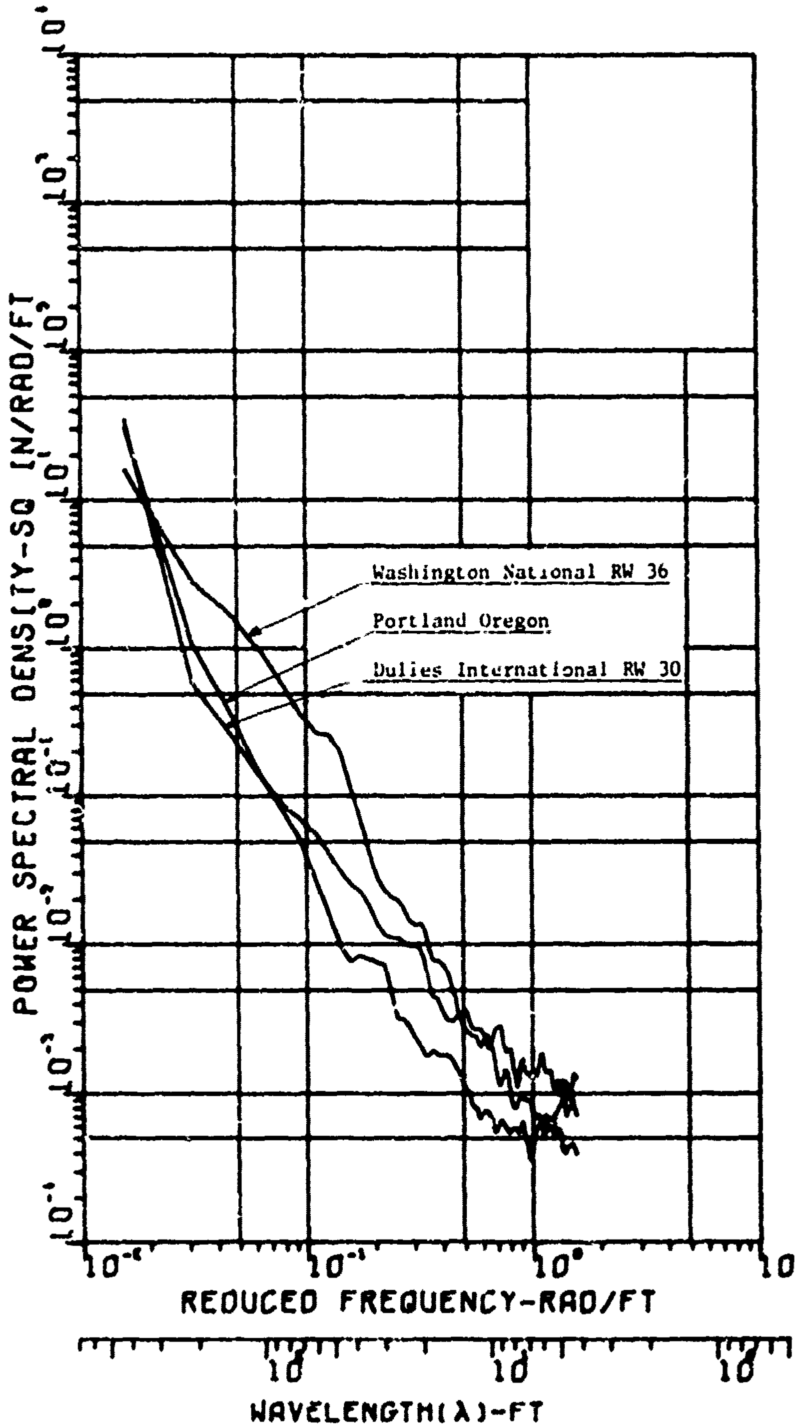

Figure 15. PSD of Washington National Runway 36 and two Typically Smooth Runways

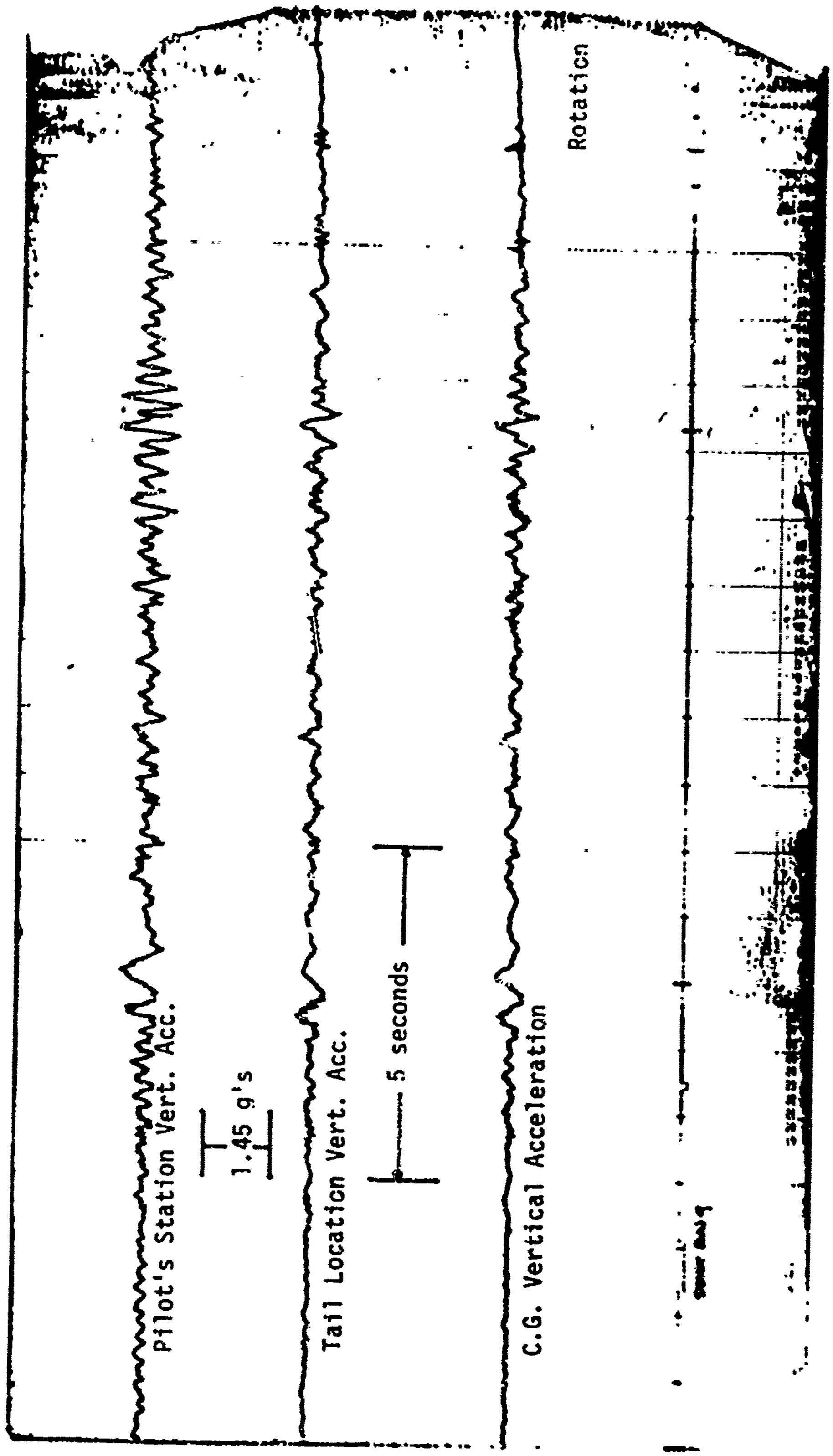

Figure 16. Measured Response of a Boeing 727-100 Takeoff at Washington National Airport Runway 36

TABLE 4

COMPARISONS OF SIMULATED AND EXPERIMENTAL DATA

Experimental Time (sec)	P.S. Vertical Acceleration		C.G. Vertical Acceleration	
	Exp (g's)	Sim (g's)	Exp (g's)	Sim (g's)
8.0	0.9425	0.90	0.55	0.35
16.3	1.305	1.12	0.80	0.40
20.5		TAKEOFF		

Note: All measurements are measured from peak to peak.

The remaining simulations made were with the inclusion of wing flexibility in the simulations. The purpose of including the wing flexibility was to see if there was a significant change in P.S. and C.G. vertical acceleration response when the wing was permitted to bend when acted on by a main landing gear strut force. These simulations were made on the C-9A only because this was the only aircraft for which wing flexibility data was available. Figure 17 shows the plotted results of C-9A with flexibile wings traversing the 1-cos dip at a 45° angle. This figure can be compared to Figure 10 which is the same simulation without flexible wings. By superimposing the two plots it was determined after T=17 seconds, small changes in vertical acceleration were appearing in both the P.S. and C.G. responses. Generally the higher accelerations occurred on the C-9A simulation with flexible wings. Also there was a phase lag. By the end of the run the rigid wing model lagged the flexible wing model by approximately one half of a cycle. Figure 18 shows the plotted response of the C-9A with flexible wings during a takeoff simulation from Washington National Runway 36. Figure 14 shows the same simulation without flexible wings. Superposition of the two plots shows little change, if any, in the airplane's response.

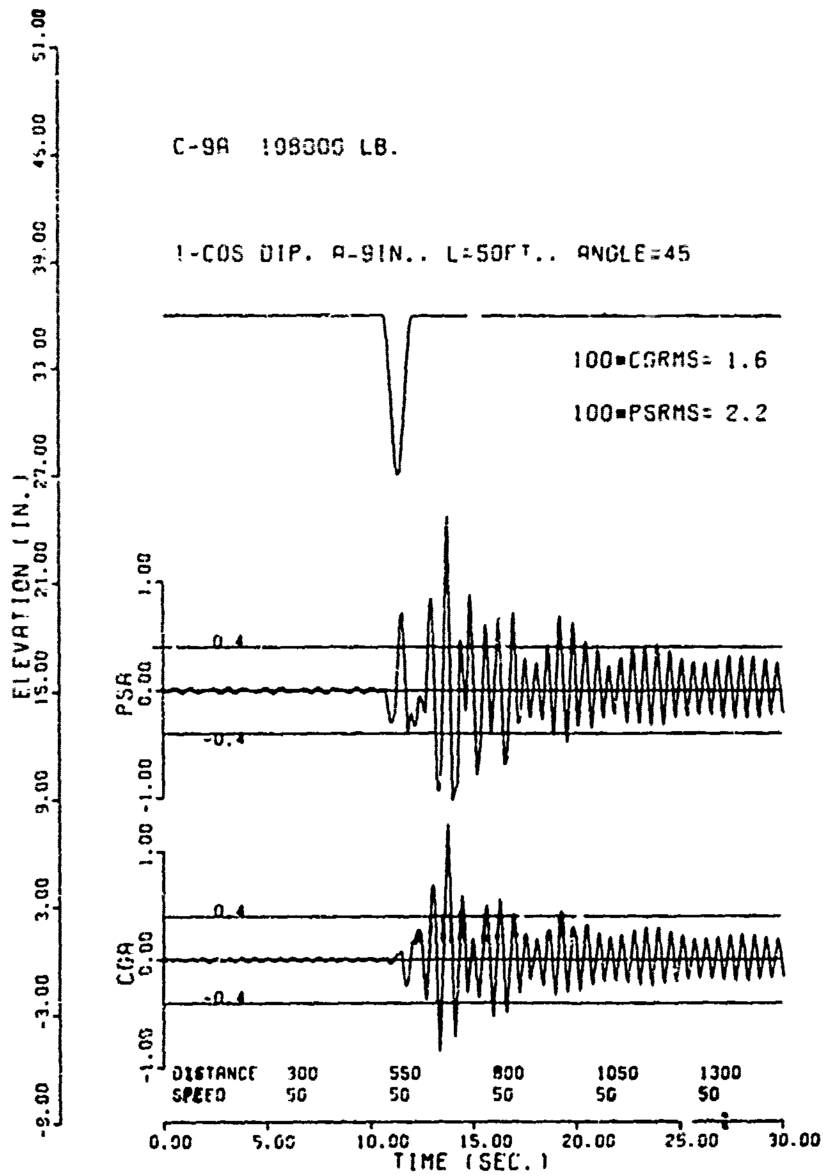

Figure 17. C-9A with Flexible Wings Taxiing over a (1-cos) dip at a 45° angle

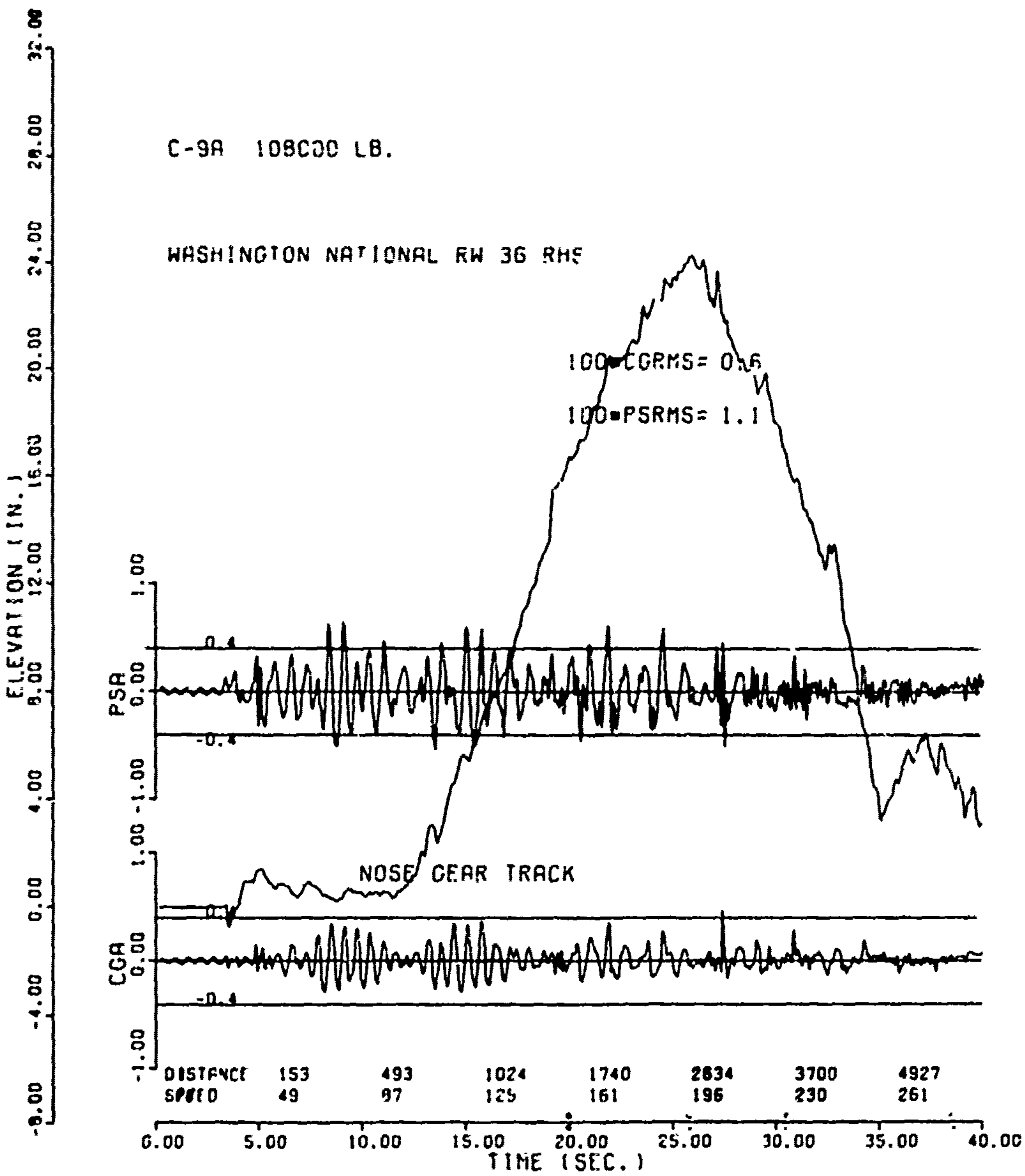

Figure 18. C-9A with Flexible Wings Taking Off from Washington National Runway 36

SECTION V
SUMMARY AND CONCLUSIONS

In summary, a mathematical model has been formulated and programmed for a digital computer and is capable of simulating most flexible aircraft traversing an unsymmetric runway profile during constant speed taxi or takeoff. Three different aircraft have been simulated and comparisons have been made with experimental data.

Based on the 11 simulations made, the following conclusions were drawn:

1. The roll degree of freedom has a significant effect on the pilot's station and center of gravity vertical acceleration levels if the runway profile is asymmetric. The degree is dependent upon how asymmetric the profile is.

2. The effect of wing flexibility on P.S. and C.G. vertical acceleration response is small enough to be neglected, at least for the airplane simulated (C-9A). However, with the addition of flexible wings, it now becomes an easy matter to expand the computer program to obtain vertical accelerations (and consequently shears and moments) at vital wing stations such as the wing root and engine and stores pylons. This would be a natural extension of the study.

3. Comparison of the simulated aircraft response with the limited amount of available test data was satisfactory. The roughest parts of the runway were identified and, as in the test, pilot station acceleration levels exceeded the $\pm 0.4g$ criterion. If exact strut and tire pressures, and inertia's were known for the test aircraft, the simulated C.G. response may have more closely matched the experimental data.

The simulated takeoff took an additional 5 seconds to reach rotation speed. It is assumed that the actual test aircraft weight was less than 120,000 pounds, because several runs were made without refueling the aircraft after each run. Therefore, some of the fuel had been burned off. The fact that the airplane was lighter than that simulated would also contribute to the difference in C.G. response. Also, using a 15° flap setting changed the value of C_L and resulted in a shorter takeoff distance.

4. This computer program, "TAX2", appears to be a very efficient technique for locating the rough areas of an asymmetric runway. Using a CDC 6600 digital computer, a C-9A takeoff simulation required 70 seconds of central processor (CP) computer time, which is just 30 seconds over real time for this simulation. These numbers are typical for most simulations.

One of the advantages of a program of this type is that runway repairs can be simulated before the actual repair is made in order to determine the minimum amount of repair required. In addition, the effect of the proposed repair on other aircraft can be determined before the repair is made.

APPENDIX A
DEVELOPMENT OF EQUATIONS OF MOTION

Development of equations of motion using Lagrange equations. All symbols refer to Figure A-1.

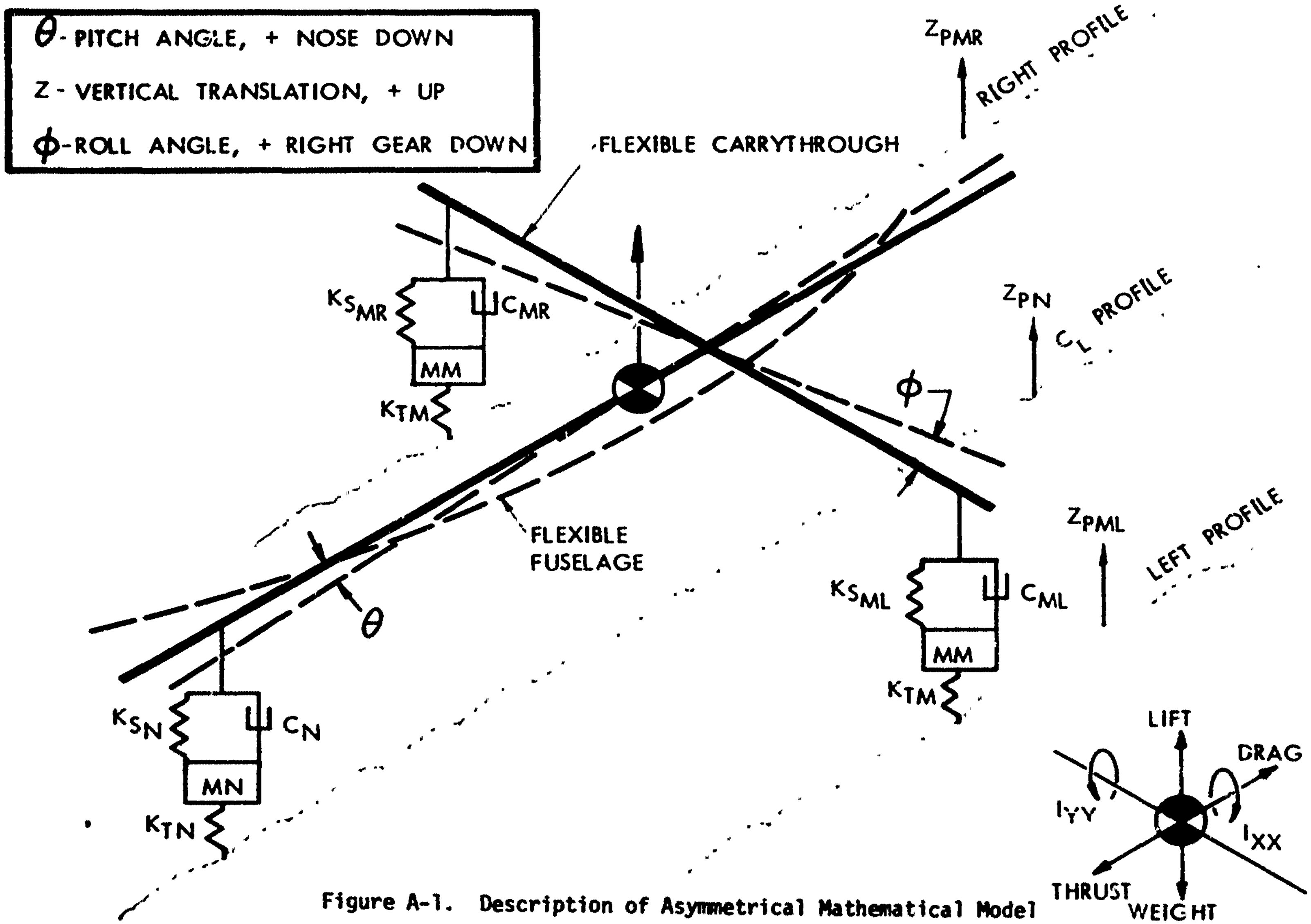

Figure A-1. Description of Asymmetrical Mathematical Model

Using Lagrange

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{q}_i} - \frac{\partial KE}{\partial q_i} + \frac{\partial PE}{\partial q_i} + \frac{\partial DE}{\partial \dot{q}_i} = 0$$

The Kinetic Energy is:

$$K.E. = \tfrac{1}{2} M\dot{Z}_{cg}^2 + \tfrac{1}{2} M_M \dot{Z}_{MR}^2 + \tfrac{1}{2} M_M \dot{Z}_{ML}^2$$

$$+ \tfrac{1}{2} M_N \dot{Z}_N^2 + \tfrac{1}{2} I_{yy}\dot{\Theta}^2 + \tfrac{1}{2} I_{xx}\dot{\phi}^2$$

The Potential Energy is:

$$P.E. = + W_M Z_{MR} + W_M Z_{ML} + W_N Z_N + WZ_{cg} - L\, Z_{cg}$$

$$+ \tfrac{1}{2} K_{SML}(Z_{cg} + A\Theta - Z_{ML} - C\phi)^2 + \tfrac{1}{2} K_{TM}(Z_{ML} - Z_{PML})^2$$

$$+ \tfrac{1}{2} K_{SMR}(Z_{cg} + A\Theta - Z_{MR} + C\phi)^2 + \tfrac{1}{2} K_{TM}(Z_{MR} - Z_{PMR})^2$$

$$+ \tfrac{1}{2} K_{SN}(Z_{cg} - B\Theta - Z_N)^2 + \tfrac{1}{2} K_{TN}(Z_N - Z_{PN})^2$$

The Dissipative Energy is:

$$D.E. = + \tfrac{1}{2} C_{ML}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi})^2$$

$$+ \tfrac{1}{2} C_{MR}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi})^2$$

$$+ \tfrac{1}{2} C_N(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_N)^2$$

Now Find $\dfrac{d}{dt}\dfrac{\partial KE}{\partial \dot{q}_i}$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{cg}} = M\ddot{Z}_{cg} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_N} = M_N\ddot{Z}_N$$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{MR}} = M_M\ddot{Z}_{MR} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{\Theta}} = I_{yy}\ddot{\Theta}$$

$$\frac{d}{dt}\frac{\partial KE}{\partial \dot{Z}_{ML}} = M_M\ddot{Z}_{ML} \; ; \; \frac{d}{dt}\frac{\partial KE}{\partial \dot{\phi}} = I_{xx}\ddot{\phi}$$

$$\frac{\partial KE}{\partial q_i} = 0$$

Now Find $\frac{\partial(P.E)}{\partial q_i}$

$$\frac{\partial(P.E)}{\partial Z_{cg}} = + K_{SML}(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}(Z_{cg} + A\Theta - Z_{MR} + C\phi) + K_{SN}(Z_{cg} - B\Theta - Z_N) + W - L$$

$$\frac{\partial(P.E)}{\partial Z_{MR}} = + W_M - K_{SMR}(Z_{cg} + A\Theta - Z_{MR} + C\phi) + K_{TM}(Z_{MR} - Z_{PMR})$$

$$\frac{\partial(P.E)}{\partial Z_{ML}} = + W_M - K_{SML}(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{TM}(Z_{ML} - Z_{PML})$$

$$\frac{\partial(P.E)}{\partial Z_N} = + W_N - K_{SN}(Z_{cg} - B\Theta - Z_N) + K_{TN}(Z_N - Z_{PN})$$

$$\frac{\partial(P.E)}{\partial \Theta} = + K_{SML}A(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}A(Z_{cg} + A\Theta - Z_{MR} + C\phi) - K_{SN}B(Z_{cg} - B\Theta - Z_N)$$

$$\frac{\partial(P.E)}{\partial \phi} = - K_{SML}C(Z_{cg} + A\Theta - Z_{ML} - C\phi) + K_{SMR}C(Z_{cg} + A\Theta - Z_{MR} + C\phi)$$

Now Find $\frac{\partial(D.E)}{\partial \dot{q}_i}$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{MR}} = - C_{MR}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi})$$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{ML}} = -\,C_{ML}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi})$$

$$\frac{\partial(D.E)}{\partial \dot{Z}_{N}} = -\,C_{N}(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N})$$

$$\begin{aligned} \frac{\partial(D.E)}{\partial \dot{Z}_{cg}} = &+ C_{MR}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) \\ &+ C_{ML}(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi}) \\ &- C_{N}(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N}) \end{aligned}$$

$$\begin{aligned} \frac{\partial(D.E)}{\partial \dot{\Theta}} = &+ C_{MR}A(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) \\ &+ C_{ML}A(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{ML} - C\dot{\phi}) \\ &- C_{N}B(\dot{Z}_{cg} - B\dot{\Theta} - \dot{Z}_{N}) \end{aligned}$$

$$\begin{aligned} \frac{\partial(D.E)}{\partial \dot{\phi}} = &+ C_{MR}C(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} + C\dot{\phi}) \\ &- C_{ML}C(\dot{Z}_{cg} + A\dot{\Theta} - \dot{Z}_{MR} - C\dot{\phi}) \end{aligned}$$

<u>Combine Terms</u>

$$\begin{aligned} M\ddot{Z}_{cg} = &- K_{SML}[Z_{cg} + \overset{(X_{ML})}{A\Theta - Z_{ML}} - C\phi] \\ &- K_{SMR}[Z_{cg} + \overset{(X_{MR})}{A\Theta - Z_{MR}} + C\phi] \\ &- K_{SN}[Z_{cg} - \overset{(X_{N})}{B\Theta - Z_{N}}] - W + L \\ &- C_{MR}[\dot{Z}_{cg} + \overset{(\dot{X}_{MR})}{A\dot{\Theta} - \dot{Z}_{MR}} + C\dot{\phi}] \\ &- C_{ML}[\dot{Z}_{cg} + \overset{(\dot{X}_{ML})}{A\dot{\Theta} - \dot{Z}_{ML}} - C\dot{\phi}] \\ &- C_{N}[\dot{Z}_{cg} - \overset{(\dot{X}_{N})}{B\dot{\Theta} - \dot{Z}_{N}}] \end{aligned}$$

<u>Rewriting we have</u>

$$M\ddot{Z}_{cg} = [-K_{SML}(X_{ML}) - C_{ML}(\dot{X}_{ML})] + \qquad (1)$$

$$[-K_{SMR}(X_{MR}) - C_{MR}(\dot{X}_{MR})] +$$

$$[-K_{SN}(X_N) - C_N(\dot{X}_N)] - W + L$$

where the terms in the brackets are the left, right, and nose landing gear strut forces respectively.

Similarly

$$M_M\ddot{Z}_{ML} = K_{SML}(X_{ML}) + C_{ML}(\dot{X}_{ML}) - K_{TM}(Z_{ML} - Z_{PML}) - W_M \tag{2}$$

$$M_M\ddot{Z}_{MR} = K_{SMR}(X_{MR}) + C_{MR}(\dot{X}_{MR}) - K_{TM}(Z_{MR} - Z_{PMR}) - W_M \tag{3}$$

$$M_N\ddot{Z}_N = K_{SN}(X_N) + C_N(\dot{X}_N) - K_{TN}(Z_N - Z_{PN}) \tag{4}$$

$$I_{yy}\ddot{\Theta} = - K_{SML}A(X_{ML}) + C_{ML}A(\dot{X}_{ML}) + K_{SMR}A(X_{MR}) + C_{MR}A(\dot{X}_{MR}) - K_N B(X_N) + C_N B(X_N) \tag{5}$$

$$I_{xx}\ddot{\phi} = K_{SML}C(X_{ML}) + C_{ML}C(\dot{X}_{ML}) - K_{SMR}C(X_{MR}) - C_{MR}C(\dot{X}_{MR}) \tag{6}$$

The Forward Translation Equation of Motion is uncoupled and expressed as follows:

$$M\ddot{X} = T - D_a - D_t$$

where:

T = Thrust

D_a = Aerodynamic Drag

D_t = Tire Drag (Total)

The modal method will be used to express the aircraft's flexibility as follows:

$$M_i \ddot{q}_i = \xi_{ij} F_j - 2\zeta\omega_i M_i \dot{q}_i - \omega_i^2 M_i q_i$$

where i = the ith mode

F_j = the jth force input into the system (such as strut force)

M_i = the ith generalized mass

q_i = the generalized coordinate

ξ_{ij} = the modal deflection of the ith mode at fuselage station j for symmetric modes or wing station j for asymmetric modes.

ω_i = the ith mode natural frequency

ζ = Structural damping factor

By using this technique the displacements X'_{MR}, X'_{ML}, X'_N and their time derivatives reflect the motion of the bending fuselage and wings by adding the $\sum_{i=1}^{N} q_i \xi_{ij}$ (modal displacements) at the jth (required location).

For example;

Total Displacement $X'_{MR} = X_{MR} + \sum_{i=1}^{N} q_i \xi_{iR} + \sum_{k=1}^{P} q_k \xi_{kR}$

Total Velocity $\dot{X}'_{MR} = \dot{X}_{MR} + \sum_{i=1}^{N} \dot{q}_i \xi_{iR} + \sum_{k=1}^{P} \dot{q}_k \xi_{kR}$

where:

Term 1 = Displacements of the rigid body

Term 2 = Displacements due to the symmetric modes

Term 3 = Displacements due to the asymmetric modes

APPENDIX B
LISTING OF COMPUTER PROGRAM TAX2

BEST AVAILABLE COPY

```
PROGRAM TAX2        74/74    OPT=1                         FTN 4.5+R436        05/25/76  13.22.28        PAGE     1

      PROGRAM TAX2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PLOT,TAPE2,    TAX20010
     1TAPE3,TAPE4)                                                      TAX20020
*********************************************************************TAX20030
*********************************************************************TAX20040
*********************************************************************TAX20050
C  THIS PROGRAM WILL PERFORM A SYMMETRIC                               TAX20060
C  DYNAMIC TAXI ANALYSIS ON A FLEXIBLE                                 TAX20070
C  VEHICLE WITH ROLL TRAVERSING A GIVEN RIGID RUNWAY                   TAX20080
C  PROFILE.                                                            TAX20090
*********************************************************************TAX20100
*********************************************************************TAX20110
*********************************************************************TAX20120
      COMMON/FLEX1/SIMAIN(15),SINOSE(15),SPOD(15),SITAIL(15),SIPS(15)   TAX20130
      COMMON/FLEX2/NFM,SM(15),OMEGA(15),DA  AA(15),SMA(15)              TAX20140
      COMMON/FLEX3/Q(15),QD(15),QDD(15)                                 TAX20150
      COMMON/FLEX4/QA(15),QDA(15),QDDA(15),NAFM,SILEFT(15),SIRIGHT(15)  TAX20160
      DIMENSION SILEFT(15),SMA(15),OMEGAA(15),QDDA(15),QDA(15),QA(15)   TAX20170
      COMMON/X1/M,MM,WN,HCG,MM,MN,A,G,MMI ,MMI2                         TAX20180
      COMMON/X2/PADM,VOM,AAM,AMM,DAM                                    TAX20190
      COMMON/X3/PADN,VON,AAN,AMN,DAN                                    TAX20200
      COMMON/X4/SXM,SYN,SLM,SLN,TSM ,TSN                                TAX20210
      COMMON/X5/CL,CD,AREA,THRUST                                       TAX20220
      COMMON/X6/Z,RFACTM,RFACTN,DT,NTRUN,SPEED                          TAX20230
      COMMON/X7/AM,BM,CM,DM,AN,BN,CN,DN,AMR,BMR,CMR,DMR                 TAX20240
      COMMON/X8/STROKM(20),PINDM(20),STROKN(20),PINDN(20),NSCM,NSCN     TAX20250
      COMMON/X9/FSM,FSN,FTM,FTN,XMAIN,XNOSE,VELM,VELN                   TAX20260
       COMMON/X99/FSML,FSMR,FTML,FTMR,XMAINL,XMAINR,VELML,VELMR,WS      TAX20270
      COMMON/X10/ZPM,ZPN,ZPML,ZPMR                                      TAX20280
      COMMON/20/COML,SSML,AOML                                          TAX20290
      DIMENSION PLANE(8),SITE(4)                                        TAX20300
      DIMENSION ELEV(5000),ELEVL(5000),ELEVR(5000)                      TAX20310
      DIMENSION T(12), TD(12), TDD(12)                                  TAX20320
      DIMENSION YPL(6),YPM(6),            YPR(6)                        TAX20330
      DIMENSION CGACC(1900), TIME(1900), PSACC(1900), TIMEV(1900)       TAX20340
      DIMENSION PROF(1800),RMARK(20)                                    TAX20350
      DIMENSION SSPLOT(300), STIME(300),DDPLOT(300)                     TAX20360
      REAL HCG,MM,MN,MMI,MMI2                                           TAX20370
      PSA=0.0                                                           TAX20380
      CGOUT=0.0                                                         TAX20390
      LOK=0                                                             TAX20400
      NOR=0.                                                            TAX20410
      X=0.                                                              TAX20420
      LLL = 1                                                           TAX20430
      LL = 0                                                            TAX20440
      STORE1 = 0.                                                       TAX20450
      STORE2 = 0.                                                       TAX20460
      STORE3 = 0.                                                       TAX20470
      STORE4 = 0.                                                       TAX20480
      NN = 0                                                            TAX20490
      II = 0                                                            TAX20500
      PP = 1.0                                                          TAX20510
      M = 1                                                             TAX20520
      ITT = 0                                                           TAX20530
*********************************************************************TAX20540
C        READ AND PRINT INPUT DATA                                      TAX20550
*********************************************************************TAX20560
C   W=VEHICLE WEIGHT AT CG (POUNDS)                                     TAX20570
```

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PROGRAM TAXI        74/74    OPT=1                         FTN 4.5+P406        05/25/76  13.22.24        PAGE    2

      C   A=DISTANCE MAIN GEAR TO CG (INCHES)                               TAX20580
      C   B=DISTANCE NOSE GEAR TO CG (INCHES)                               TAX20590
      C MMI=MASS MOMENT OF INERTIA (LB IN SEC SQ)                           TAX20600
      C     MS  WING STATION OF MLG (INCHES)                                TAX20610
      C      MMIR   MASS MOMENT OF INERTIA IN ROLL (LB IN SEC SQ)           TAX20620
      C  PLANE= AIRPLANE BEING SIMULATED AND  GROSS WEIGHT                  TAX20630
      C  PSARM = DISTANCE OF PILOT STATION TO CG                            TAX20640
      C      TAILRM = DISTANCE OF TAIL STATION TO CG                        TAX20650
      C  TAKOFF= TAKE-OFF SPEED (FEET/SEC)                                  TAX20660
      C SPEED =INITIAL  VEL  OF  AIRPLANE                                   TAX20670
      C  THURST= TOTAL AIRPLANE THRUST                                      TAX20680
      C  CL=LIFT COEFF.                                                     TAX20690
      C  AREA=WING AREA                                                     TAX20700
      C  CD=DRAG COEFF.                                                     TAX20710
      C  WM=WEIGHT OF MAIN GEAR  (EACH)                                     TAX20720
      C  WN=WEIGHT OF NOSE GEAR                                             TAX20730
      C  SKM= NUMBER OF MAIN GEAR STRUTS                                    TAX20740
      C   SKN= NUMBER OF NOSE GEAR STRUTS                                   TAX20750
      C AHN  HYDRAULIC PISTON AREA NOSE SQ INCHES                           TAX20760
      C AAN  PNEUMATIC PISTON AREA NOSE SQ INCHES                           TAX20770
      C AHM  HYDRAULIC PISTON AREA MAIN SQ INCHES                           TAX20780
      C AAM  PNEUMATIC PISTON AREA MAIN SQ INCHES                           TAX20790
      C PAON NOSE STRUT PRELOAD PRESSURE  PSI                               TAX20800
      C PAOM MAIN STRUT PRELOAD PRESSURE  PSI                               TAX20810
      C VON  NOSE STRUT INITIAL VOLUME CU. IN.                              TAX20820
      C VOM  MAIN STRUT INITIAL VOLUME CU. IN.                              TAX20830
      C OAM  ORIFACE AREA MAIN                                              TAX20840
      C OAN  ORIFACE AREA NOSE                                              TAX20850
      C SLM=MAIN GEAR STRUT LENGTH UNLOADED INCHES                          TAX20860
      C      DISTANCE FROM CL OF AXLE TO CG LINE                            TAX20870
      C SLN=NOSE GEAR STRUT LENGTH UNLOADED INCHES                          TAX20880
      C      DISTANCE FROM CL OF AXLE TO CG LINE                            TAX20890
      C  TSM     MAIN TIRE SPRING CONSTANT PER STRUT                        TAX20900
      C  TSN     NOSE TIRE SPRING CONSTANT PER STRUT                        TAX20910
      C  DT=TIME STEP SIZE                                                  TAX20920
      C  READ METERING PIN DESCRIPTION STARTING AT ZERO STROKE              TAX20930
      C  NSCN=# OF METERING PIN CHANGES NOSE GEAR                           TAX20940
      C  NSCM=# OF METERING PIN CHANGES MAIN GEAR                           TAX20950
      C  NFM = NUMBER OF FLEXIBLE MODES                                     TAX20960
      C  NAFM= NUMBER OF ASYMMETRIC MODES                                   TAX20970
      C  SIXXXX(I) = MODE SHAPE DEFLECTION (NON DIM.)                       TAX20980
      C  GM(I) = GENERALIZED MASS (POUNDS-SEC SQ/IN)                        TAX20990
      C  OMEGA (I) = MODAL FREQUENCIES (RAD/SEC)                            TAX21000
      C  SILEFT(I)= LEFT GEAR MODE SHAPE DEFLECTION                         TAX21010
      C  SIRIGHT(I)=RIGHT GEAR MODE SHAPE DEFLECTION                        TAX21020
      C  GMA(I)= ASYM. MODE GEN. MASS                                       TAX21030
      C  OMEGAA(I)= ASYM. MODE FREQ.                                        TAX21040
            READ (5,1) PLANE                                                TAX21050
        1   FORMAT(8A10)                                                    TAX21060
            READ(5,5) W,A,B,MMI,MS,MMIR                                     TAX21070
       5    FORMAT(4F10.1,2F12.0)                                           TAX21080
            READ(5,10) PSARM,TAILRM                                         TAX21090
        10  FORMAT(2F10.2)                                                  TAX21100
            READ(5,15) SPEED,THRUST,TAKOFF                                  TAX21110
        15  FORMAT(3F10.3)                                                  TAX21120
            READ(5,20) CL,AREA,CD                                           TAX21130
        20  FORMAT(3F10.4)                                                  TAX21140
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PROGRAM TAX2        75/76    OPT=1                    FTN 4.5+R406        05/25/75  10.22.70        PAGE     3

      READ(5,25) WM,WN,SXM,SXN                                                   TAX21150
   25 FORMAT(4F10.2)                                                             TAX21160
      READ(5,30) AMN,AAN,AMM,AAM                                                 TAX21170
   30 FORMAT(4F10.5)                                                             TAX21180
      READ(5,35) PAON,PAOM,VON,VOM,DAM,DAN                                       TAX21190
   35 FORMAT(6F10.5)                                                             TAX21200
      READ(5,40) SLM,SLN                                                         TAX21210
   40 FORMAT(2F10.3)                                                             TAX21220
      READ(5,45) TSM ,TSN                                                        TAX21230
   45 FORMAT(2F10.1)                                                             TAX21240
      READ(5,50)DX                                                               TAX21250
      READ(5,51)IFPLOT,IFLIST                                                    TAX21260
   50 FORMAT(F10.3)                                                              TAX21270
      READ(5,51) NSCN                                                            TAX21280
   51 FORMAT(2I5)                                                                TAX21290
      READ(5,52) (STROKN(I),PINDN(I),I=1,NSCN)                                   TAX21300
   52 FORMAT(2(F10.3))                                                           TAX21310
      READ(5,51)NSCM                                                             TAX21320
      READ(5,52) (STROKM(I),PINDM(I),I=1,NSCM)                                   TAX21330
      READ(5,51) NFM,NAFM                                                        TAX21340
      READ(5,53) (SIMAIM(I),SINOSE(I),SICG(I),SITAIL(I),SIPS(I)                  TAX21350
     1,I=1,NFM)                                                                  TAX21360
   53 FORMAT(5F10.7)                                                             TAX21370
      READ(5,54) (GM(I),OMEGA(I),I=1,NFM)                                        TAX21380
   54 FORMAT(F15.3,F10.4)                                                        TAX21390
       READ(5,53)(SILEFT(I),SIRIGHT(I),I=1,NAFM)                                 TAX21400
      READ(5,54)(GMA(I),OMEGAA(I),I=1,NAFM)                                      TAX21410
      WM=WM/386.                                                                 TAX21420
      WN=WN/386.                                                                 TAX21430
      WCG=W/386.                                                                 TAX21440
      TYPRUN = .01                                                               TAX21450
      IF(SPEED.GT.5.) TYPRUN = .02                                               TAX21460
      NTRUN=TYPRUN*100.                                                          TAX21470
      WRITE(6,55)                                                                TAX21480
   55 FORMAT(1H1,45X,********************************************)             TAX21490
      WRITE(6,60)                                                                TAX21500
   60 FORMAT(46X,46H****************** INPUT DATA ******************)           TAX21510
      WRITE(6,61)                                                                TAX21520
   61 FORMAT(///1X,41H********** GENERAL AIRCRAFT DATA **********)              TAX21530
      WRITE(6,62)PLANE                                                           TAX21540
   62 FORMAT(//,1X,8A10)                                                         TAX21550
      WRITE(6,65) W,WM,WN,A,B, WS,WMI,WMIR                                       TAX21560
   65 FORMAT(///,5X,*W=*,F10.1,5X,*WM=*,F10.2,3X,*WN=*,F10.2,5X,                TAX21570
     1*A=*,F10.3,5X,*B=*,F10.3,5X,*WS=*,F10.3,3X,*WMI=*,F12.0,///,5X,          TAX21580
     1*WMIR=*,F12.0)                                                             TAX21590
      WRITE(6,66) SXM,SXN,SLM,SLN,PSARM,TAILRM                                   TAX21600
   66 FORMAT(//,5X,*SXM=*,F9.1,5X,*SXN=*,F9.1,5X,*SLM=*,F9.1,5X,                TAX21610
     1*SLN=*,F9.1,5X,*PSARM=*,F7.1,4X,*TAILRM=*,F7.1)                           TAX21620
      WRITE(6,70) AAN,AMN,PAON,VON,DAN,TSN                                       TAX21630
   70 FORMAT(//,5X,*AAN=*,F9.2,5X,*AMN=*,F9.2,5X,*PAON=*,F9.2,4X,              TAX21640
     1*VON=*,F9.2,5X,*DAN=*,F9.2,5X,*TSN =*,F13.2)                              TAX21650
      WRITE(6,76) AAM,AMM,PAOM,VOM,DAM,TSM                                       TAX21660
   76 FORMAT(//,5X,*AAM=*,F9.2,5X,*AMM=*,F9.2,5X,*PAOM=*,F9.2,4X,              TAX21670
     1*VOM=*,F9.2,5X,*DAM=*,F9.2,5X,*TSM =*,F13.2)                              TAX21680
      WRITE(6,75) CL,CD,AREA,SPEED,THRUST,TAKOFF                                 TAX21690
   75 FORMAT(//,5X,*CL=*,F9.3,5X,*CD=*,F9.3,6X,*AREA=*,F8.2,5X,                TAX21700
     1*SPEED=*,F7.1,4X,*THRUST=*,F7.0,7X,*TAKOFF=*,F10.2)                      TAX21710
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PROGRAM TAX2       74/74    OPT=1                              FTN 4.5+R406       09/25/75  10.22.20       PAGE     4

           WRITE(6,76) (STROKN(I),PINON(I),I=1,NSCN)                                  TAX21720
      76   FORMAT(//,3X,*STROKE NOSE    PIN DIAMETER    *//,2(3X,F10.3))              TAX21730
           WRITE(6,77) (STROKM(I),PINOM(I),I=1,NSCM)                                  TAX21740
      77   FORMAT(//,3X,*STROKE MAIN    PIN DIAMETER     *//,2(3X,F10.3))             TAX21750
           WRITE(6,80)                                                                TAX21760
      80   FORMAT(1H1,1X,*MODE  SI*S    SINOSE*,6X,*  SICG    SIMAIN  SITAIL          TAX21770
          1OMEGA  GEN. MASS*)                                                         TAX21780
           DO 85  I=1,NFM                                                             TAX21790
      85   WRITE(6,90 )(I,SI*S(I),SINOSE(I),SICG(I),SIMAIN(I),SITAIL(I),              TAX21800
          1OMEGA(I),GM(I))                                                            TAX21810
            WRITE(6,86)                                                               TAX21820
      86   FORMAT(//,*ASSYMETRICAL MODES*,/,1X,*MODE*,5X,*SIRIGHT*,5X,                TAX21830
          1*SILEFT*,5X,*OMEGAA*,5X,*GEN MASS*)                                        TAX21840
            DO 88 I=1,NAFM                                                            TAX21850
            WRITE(6,87)(I,SIRIGHT(I),SILEFT(I),OMEGAA(I),GMA(I))                      TAX21860
      88   CONTINUE                                                                   TAX21870
      87   FORMAT(1X,I5,3X,4(F10.3,1X))                                               TAX21880
      90    FORMAT(//,     2X,I2,6(F7.2,2X),F10.1)                                    TAX21890
     C ZMI =INITIAL MAIN GEAR POSITION INCHES                                         TAX21900
           WRITE(6,95)                                                                TAX21910
      95   FORMAT(///,46X,45H********** INTIAL CONDITIONS ************)               TAX21920
     C ZNI =INITIAL NOSE GEAR POSITION INCHES                                         TAX21930
     C ZCGI=INITIAL C.G. POSITION INCHES                                              TAX21940
     C THETAI=INITIAL PITCH ANGLE DEGREES                                             TAX21950
     C   THE ABOVE PARAMETERS ARE CALCULATED IN SUBROUTINE IC                         TAX21960
           CALL IC(  ZCGI,ZMI,ZNI,THETAI)                                             TAX21970
            ZMIL=ZMI                                                                  TAX21980
            ZMIR=ZMI                                                                  TAX21990
           WRITE(6,105) ZMI,ZNI,THETAI,ZCGI                                           TAX22000
     105   FORMAT(//,5X,4HZMI=,F10.3,5X,4HZNI=,F10.3,5X,7HTHETAI=,F10.6,              TAX22010
          15X,5HZCGI=,F10.3,*BETA=0.*)                                                TAX22020
           BETA=0.                                                                    TAX22030
           REACTN=(ZNI TSN )*SXN                                                      TAX22040
           REACTM=(ZMI*TSM )*SXM                                                      TAX22050
           WRITE(6,106) XMAIN,XNOSE,REACTM,REACTN                                     TAX22060
     106   FORMAT (/,3X,*XMAIN=*,F8.3,3X,*XNOSE=*,F8.3,3X,*REACTM=*,F10.0,            TAX22070
          13X,*REACTN=*,F10.0)                                                        TAX22080
           XMAINR=X..AIN                                                              TAX22090
     ************************************************************************TAX22100
     C READ RUNWAY PROFILE DATA  ELEVL,ELEV,ELER                                      TAX22110
     C   SITE= RUNWAY PROFILE AND DIRECTION                                           TAX22120
     C  NPTSS=0 OF RUNWAY ELEVATION DATA POINTS                                       TAX22130
           WRITE (6,111)                                                              TAX22140
     111   FORMAT(*1*)                                                                TAX22150
           DO 112 I=1,50                                                              TAX22160
            ELEVL(I)=0.                                                               TAX22170
            ELEVR(I)=0.                                                               TAX22180
     112   ELEV(I)=0.0                                                                TAX22190
           READ(2,1) SITE                                                             TAX22200
           READ(3,1) SITE                                                             TAX22210
           READ(4,1) SITE                                                             TAX22220
           READ(2,116) NPTSS                                                          TAX22230
           READ(3,116) NPTSS                                                          TAX22240
           READ(4,116) NPTSS                                                          TAX22250
           NPTSS=NPTSS+50                                                             TAX22260
     116   FORMAT(I5)                                                                 TAX22270
           LO=51                                                                      TAX22280
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PROGRAM TAX2        74/74    OPT=1                    FTN 4.5+P408        05/25/76  10.22.70        PAGE     5

      117  LSD = LD + 9                                                    TAX22290
           READ(2,118) (ELEVL(I),I=LD,LSD)                                 TAX22300
           READ(3,118) (ELEV(I),I=LD,LSD)                                  TAX22310
           READ(4,118) (ELEVR(I),I=LD,LSD)                                 TAX22320
      118  FORMAT(10F7.3)                                                  TAX22330
           M10=LD                                                          TAX22340
           IF(LSD.GE.NPTSS) GO TO 120                                      TAX22350
           LD=LD+10                                                        TAX22360
           GO TO 117                                                       TAX22370
      120  ELEV1=ELEV(S1)                                                  TAX22380
           ELEV2=ELEVL(S1)                                                 TAX22390
           ELEV3=ELEVR(S1)                                                 TAX22400
           DO 125 I=S1,M10                                                 TAX22410
           ELEVL(I) = (ELEVL(I)-ELEV2)*12.0                                TAX22420
           ELEVR(I) = (ELEVR(I)-ELEV3)*12.0                                TAX22430
      125  ELEV(I) = (ELEV(I)-ELEV1)*12.0                                  TAX22440
           DISTAN=0.                                                       TAX22450
           LSD=LSD-90                                                      TAX22460
           SLP=(LSD-S0)*2                                                  TAX22470
           SLP=ELEV(LSD)/SLP                                               TAX22480
           DO 126 I=S1 ,M10                                                TAX22490
           ELEV(I) =ELEV(I) -SLP*DISTAN                                    TAX22500
           ELEVR(I)=ELEVR(I)-SLP*DISTAN                                    TAX22510
           ELEVL(I)=ELEVL(I)-SLP*DISTAN                                    TAX22520
      126  DISTAN=DISTAN+2.                                                TAX22530
           IVAL=(A+R)/24.                                                  TAX22540
           WRITE(6,130)                                                    TAX22550
      130  FORMAT(1H1,5X,*  RUNWAY PROFILE DATA NORMALIZED (SLOPE REMOVED)* TAX22560
          150X,*FEET DOWN THE RUNWAY*)                                     TAX22570
           WRITE(6,1) SITE                                                 TAX22580
           LD1=1                                                           TAX22590
      135  LSD1 = LD1 + 9                                                  TAX22600
           LPRIN = LSD1 * 2                                                TAX22610
           WRITE(6,140) (ELEV(I),I=LD1,LSD1),LPRIN                         TAX22620
      140  FORMAT(3X,10F10.5,10X,I0)                                       TAX22630
           LD1=LD1+10                                                      TAX22640
           IF(LD1.GE.M10) GO TO 145                                        TAX22650
           GO TO 135                                                       TAX22660
      145  WRITE(6,150) LD1                                                TAX22670
      150  FORMAT(42H********** END RUNWAY DATA ********** LD1=,I5)        TAX22680
           DO 161 I=1,M10,10                                               TAX22690
      161  WRITE(6,162) ELEVL(I), ELEV(I), ELEVR(I)                        TAX22700
      162  FORMAT (3(5X,F10.5))                                            TAX22710
           ENDRUN = NPTSS*2                                                TAX22720
           NRM=(ENDRUN-100.)/1000.                                         TAX22730
           RN=(((ENDRUN-100.)-FLOAT(NRM*1000))/2.)+110N.                   TAX22740
           ENDRUN=ENDRUN-99.                                               TAX22750
           T(2) =ZCGI                                                      TAX22760
           TD(2) = 0.                                                      TAX22770
           T(4) = ZMIL                                                     TAX22780
           T(5) = ZMIR                                                     TAX22790
            TD(5)=0.                                                       TAX22800
           TD(4) = 0.                                                      TAX22810
           T(6) = ZMI                                                      TAX22820
           TD(6) = 0.                                                      TAX22830
           T(8) = THETAI                                                   TAX22840
           TD(8) = 0.                                                      TAX22850
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PROGRAM TAX2        74/74    OPT=1                          FTN 4.5+R466       05/25/76  10.22.20        PAGE     6

            T(9)=BETA                                                        TAX22860
              TD(9)=0.                                                       TAX22870
            T(10) = 0.                                                       TAX22880
            IF(IFLIST.EQ.0)  WRITE(6,155)                                    TAX22960
            TD(10) = SPEED                                                   TAX22890
        155 FORMAT(1H1,*  XMAINL  XMAINR  XNOSE     ZPML     ZPMR   ZPN    BETATAX22910
          ZDD   THETADD   BETA    THETA     SPEED      DIST.     TIME    CGACTAX22920
          3C    PSA*)                                                        TAX22930
            DZ=0.                                                            TAX22940
            ZPML=0.                                                          TAX22950
            ZPMR=0.                                                          TAX22960
            ZPN=0.                                                           TAX22970
            ZLDOT=0.                                                         TAX22980
            ZRDOT=0.                                                         TAX22990
            ZNDOT=0.                                                         TAX23000
            J=1                                                              TAX23010
        100 YPL(1) = ZLDOT                                                   TAX23020
            YPR(1) = ZRDOT                                                   TAX23030
            YPL(2)=ELEVL(J)                                                  TAX23040
            YPR(2)=ELEVR(J)                                                  TAX23050
            YPL(3)=ELEVL(J+1)                                                TAX23060
            YPR(3)=ELEVR(J+1)                                                TAX23070
            YPL(4)=ELEVL(J+2)                                                TAX23080
            YPR(4)=ELEVR(J+2)                                                TAX23090
            YPN(1)=ZNDOT                                                     TAX23100
            YPN(2)=ELEV(IVAL)                                                TAX23110
            YPN(3)=ELEV(IVAL+1)                                              TAX23120
            YPN(4)=ELEV(IVAL+2)                                              TAX23130
            Z=DZ                                                             TAX23140
            CALL COEFF (YPN,AN,BN,CN,DN)                                     TAX23150
            CALL COEFF (YPL,AM,BM,CM,DM)                                     TAX23160
            CALL COEFF (YPR,AMR,BMR,CMR,DMR)                                 TAX23170
            ZLDOT=BM                                                         TAX23180
            ZRDOT=BMR                                                        TAX23190
            ZNDOT=BN                                                         TAX23200
            IF(N.GT.1) GO TO 265                                             TAX23210
            N = N + 1                                                        TAX23220
        165 IF(IFLIST.NE.0)  GO TO 764                                       TAX23230
            WRITE(3,170)XMAINL,XMAINR,XNOSE,ZPML,ZPMR,ZPN,TDD(9),TDD(8),T(9), TAX23240
           2T(8),TD(10),T(10),X,CGOUT,PSA                                    TAX23250
C           WRITE(6,731) FSML,SSML,COML,VELML,ACM.                           TAX23260
C           WRITE(6,731) T(2),T(4),T(8),T(9)                                 TAX23270
C           WRITE(6,731) TD(2),TD(4),TD(8),TD(9)                             TAX23285
        731 FORMAT(1X,6(5X,E15.8))                                           TAX23290
        764 CONTINUE                                                         TAX23300
        170 FORMAT(1X,6(2X,F6.2),4(2X,F7.2),3(2X,F8.3),2(2X,F6.3))           TAX23310
            TIMEX=0.                                                         TAX23320
*********************************************************************TAX23330
            IF(IFPLOT.EQ.1) GO TO 230                                        TAX23340
            IF(ABS(CGOUT ).LE.ABS(STORE2).AND.ABS(STORE2).GE.ABS(STORE1))    TAX23350
           1GO TO 180                                                        TAX23360
        175 STORE1 = STORE2                                                  TAX23370
            STORE2 = CGOUT                                                   TAX23380
            GO TO 190                                                        TAX23390
        180 IF(X-TIME(NN).GT..80) GO TO 185                                  TAX23400
            IF(ABS(STORE2).GT..30000) GO TO 185                              TAX23410
            GO TO 175                                                        TAX23420
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PROGRAM TAX2        74/74   OPT=1                          FTN 4.5+R406        05/25/76  10.22.29        PAGE     7

          105  NN = NN + 1                                                      TAX23430
               CGACC(NN) = STORE2                                               TAX23440
               PROF(NN) = IPM                                                   TAX23450
               TIME(NN) = X - 10. * DX                                          TAX23460
               IF(TIME(NN).LT.0.) TIME(NN) = .01                                TAX23470
               STORE1 = STORE2                                                  TAX23480
               STORE2 = CGOUT                                                   TAX23490
          190  IF(ABS(PSA).LE.ABS(STORE4).AND.ABS(STORE4).GE.ABS(STORE3))       TAX23500
              1GO TO 205                                                        TAX23510
          200  STORE3 = STORE4                                                  TAX23520
               STORE4 = PSA                                                     TAX23530
               GO TO 215                                                        TAX23540
          205  IF(X-TIME1(LL).GT..08) GO TO 210                                 TAX23550
               IF(ABS(STORE4).GT..37) GO TO 210                                 TAX23560
               GO TO 200                                                        TAX23570
          210  LL = LL + 1                                                      TAX23580
               PSACC(LL) = STORE4                                               TAX23590
               TIME1(LL)=X - 10*DX                                              TAX23600
               IF(TIME1(LL).LE.0.) TIME1(LL) = .001                             TAX23610
               STORE3 = STORE4                                                  TAX23620
               STORE4 = PSA                                                     TAX23630
          215  IF(ABS(T(10)-RM).LT.5.0) GO TO 220                               TAX23640
               GO TO 225                                                        TAX23650
          220  II = II + 1                                                      TAX23660
               RMARK(II) = X/5.                                                 TAX23670
               RM = RM + 1000.                                                  TAX23680
               ITT = II                                                         TAX23690
          225  IF(ABS(X-PP).GT..0009) GO TO 230                                 TAX23700
               SSPLOT(LLL) = TD(10)                                             TAX23710
               STIME(LLL) = X/5.                                                TAX23720
               DDPLOT(LLL) = T(10)                                              TAX23730
               LLL = LLL + 1                                                    TAX23740
               PP = PP + 5.0                                                    TAX23750
        ************************************************************************TAX23760
          230  IF(HDR.LE.80.) GO TO 235                                         TAX23770
               HDR=0.                                                           TAX23780
               IF(IFLIST.EQ.0)  WRITE(6,155)                                    TAX23790
          235  HDR = HDR + 1.                                                   TAX23800
          240  X = X + DX                                                       TAX23810
               CALL TAYLOR(T,TD,TDD)                                            TAX23820
               IF(T(10).GE.ENDRUN) GO TO 259                                    TAX23830
               IF(X.GE.300.) GO TO 261                                          TAX23840
               TIMEX=TIMEX+DX                                                   TAX23850
                QDDCG=0.                                                        TAX23860
               QDDPS=0.                                                         TAX23870
               QDDTAL=0.                                                        TAX23880
               DO 241 I=1,NFM                                                   TAX23890
                QDDTAL=QDDTAL+QDD(I)*SITAIL(I)                                  TAX23900
               QDDCG=QDDCG+QDD(I)*SICG(I)                                       TAX23910
          241   QDDPS=QDDPS+QDD(I)*SIPS(I)                                      TAX23920
               TAILAC=(TDD(2)+TAILRM*TDD(8))/386. +QDDTAL/386.                  TAX23930
               PSA=(TDD(2)-PSARM*TDD(8))/386.      +QDDPS/386.                  TAX23940
               CGOUT=TDD(2)/386.    +QDDCG/386.                                 TAX23950
               IF(TD(10).GE.TAKOFF) GO TO 250                                   TAX23960
               IF(Z.LT.4.) GO TO 265                                            TAX23970
               DZ=Z-4.                                                          TAX23980
               J=J+2                                                            TAX23990
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PROGRAM TAX2        74/74    OPT=1                    FTN 4.5+R406        05/25/76  10.22.20        PAGE      8

              IVAL=IVAL+2                                                      TAX24000
              GO TO 160                                                        TAX24010
         245  CONTINUE                                                         TAX24020
C             IF(T(10).GT.600.0) GO TO 165                                     TAX24030
              IF(TIMEX.LT.TYPRUN) GO TO 240                                    TAX24040
              GO TO 165                                                        TAX24050
         250  WRITE(6,255)                                                     TAX24060
         255  FORMAT(5X,* THE VEHICLE HAS TAKEN OFF*)                          TAX24070
         260  WRITE(6,262) EXDRUN,T(10)                                        TAX24080
         262  FORMAT(3X,* END OF RUNWAY*,2F10.3)                               TAX24090
**************************************************************************TAX24100
         2C3  MGN = I                                                          TAX24110
              PSRMS=0.                                                         TAX24120
              CGRMS=0.                                                         TAX24130
              DO 261 I=1,NN                                                    TAX24140
         261  CGRMS=CGRMS+CGACC(I)**2                                          TAX24150
              DO 264 I=1,LL                                                    TAX24160
         264  PSRMS=PSRMS+PSACC(I)**2                                          TAX24170
              PSRMS=100.*SQRT(PSRMS)/FLOAT(LL)                                 TAX24180
              CGRMS=100.*SQRT(CGRMS)/FLOAT(NN)                                 TAX24190
              WRITE(6,268) PSRMS,CGRMS                                         TAX24200
         268   FORMAT(///,3X,*100 PSRMS=*,F10.3,10X,*100 CGRMS=*,F10.3)        TAX24210
              IF(IFPLOT.EQ.1) GO TO 295                                        TAX24220
              XLONG = FLOAT(MGN)/5.                                            TAX24230
              WRITE(6,265) NN,LL                                               TAX24240
         265  FORMAT(2I20)                                                     TAX24250
              IF(NN.LE.1000.OR.LL.LE.1000) GO TO 266                           TAX24260
              WRITE(6,267)                                                     TAX24270
         267  FORMAT(5X,*THE ARRAYS CGACC OR PSACC OR PROF HAVE EXCEEDED       TAX24280
             1 THEIR DIMENSIONED SIZE*)                                        TAX24290
         266  CONTINUE                                                         TAX24300
              CALL FACTOR (2.0)                                                TAX24310
              CALL PLOT(0.0,-11.0,-3)                                          TAX24320
              CALL PLOT(3.,.7,-3)                                              TAX24330
              TIME(NN+1) = 0.0                                                 TAX24340
              TIME(NN+2) = 5.0                                                 TAX24350
              TIME1(LL+1)  =0.0                                                TAX24360
              TIME1(LL+2) = 5.0                                                TAX24370
              CGACC(NN+1) = -1.0                                               TAX24380
              CGACC(NN+2) = 1.0                                                TAX24390
              PSACC(LL+1)= -1.0                                                TAX24400
              PSACC(LL+2) = 1.0                                                TAX24410
              CALL SCALE(PROF,10.,NN,1)                                        TAX24420
              PROF10 = PROF(NN+2) *10.                                         TAX24430
              IF(PROF10.GT.10.5) GO TO 275                                     TAX24440
              PROF(NN+2) = 0.0                                                 TAX24450
              IF(NPTSS.GE.1000) GO TO 270                                      TAX24460
              DO 269 I=1,NN                                                    TAX24470
         269  PROF(I)=PROF(I)+30.                                              TAX24480
         270  CALL AXIS(0.,0.,11HTIME (SEC.),-11,XLONG,0.0,TIME(NN+1),         TAX24490
             1TIME(NN+2))                                                      TAX24500
              IXLONG = XLONG                                                   TAX24510
              CALL PLOT (XLONG,1.1,0)                                          TAX24520
              CALL PLOT (0.,1.1,2)                                             TAX24530
              CALL SYMBOL (.1,.4,.105,9HDISTANCE,0.,9)                         TAX24540
              CALL SYMBOL (.1,.2,.105,5HSPEED,0.,5)                            TAX24550
              DO 275  I=1,IXLONG                                               TAX24560
```

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```
PROGRAM TAXI        74/74   OPT=1                    FTN 4.5+R436      05/25/76  10.27.20        PAGE     9

          CALL NUMBER(STIME(I),.2,.105,SSPLOT(I),0.0,-1)                    TAX24570
     275  CALL NUMBER(STIME(I),.4,.105,DDPLOT(I),0.0,-1)                    TAX24580
          CALL PLOT (XLONG,1.5,3)                                            TAX24590
          CALL PLOT (0.,1.5,2)                                               TAX24600
          DO 280 I=1,ITT                                                     TAX24610
     280  CALL SYMBOL(XMARK(I),-.1,.245,14,0.0,1)                            TAX24620
          CALL PLOT (XLONG,1.9,3)                                            TAX24630
          CALL PLOT (0.,1.9,2)                                               TAX24640
          CALL SYMBOL(0.,9.,.14,PLANE,0.,40)                                 TAX24650
          CALL SYMBOL(9.,8.,.14,SITE,0.,40)                                  TAX24660
          CALL SYMBOL(4.,7.,.14,10H1993*CGRMS=,0.,10)                        TAX24670
          CALL SYMBOL(4.,6.5,.14,10H1999*PSRMS=,0.,10)                       TAX24680
          CALL NUMBER(5.5,7.,.14,CGRMS,0.,1)                                 TAX24690
          CALL NUMBER(5.5,6.5,.14,PSRMS,0.,1)                                TAX24700
          XLONG2=XLONG/2.                                                    TAX24710
          CALL SYMBOL(XLONG2,8.5,.14,11HAFFDL -FYS-,0.,11)                   TAX24720
          CALL SYMBOL(XLONG2,7.5,.14,13HPAFB OHIO,0.,13)                     TAX24730
          CALL PLOT(0.,1.5,-3)                                               TAX24740
          CALL AXIS(0.,-1.,3HCGA,3,2.0,90.,CGACC(NN+1),CGACC(NN+2))          TAX24750
          CALL NUMBER(0.4,-.4,.105,-.4,90.0,1)                               TAX24760
          CALL NUMBER(0.5,.4,.105,+.4,90.0,1)                                TAX24770
          CALL PLOT(0.,-1.0,-3)                                              TAX24780
          CALL LINE(TIME,CGACC,NN,1,0,76)                                    TAX24790
          CALL PLOT (XLONG,3.1,3)                                            TAX24800
          CALL PLOT (0.,3.1,2)                                               TAX24810
          CALL PLOT(0.,3.5,-3)                                               TAX24820
          CALL AXIS(0.,-1.,3HPSA,3,2.0,90.,PSACC(LL+1),PSACC(LL+2))          TAX24830
          CALL PLOT(0.,0.,3)                                                 TAX24840
          CALL PLOT(XLONG,0.,2)                                              TAX24850
          CALL PLOT (XLONG,.4,3)                                             TAX24860
          CALL PLOT (-.1,.4,2)                                               TAX24870
          CALL NUMBER(0.5,.4,.105,+.4,90.0,1)                                TAX24880
          CALL NUMBER(0.4,-.5,.105,-.4,90.0,1)                               TAX24890
          CALL PLOT(0.,-1.0,-3)                                              TAX24900
          CALL LINE(TIME1,PSACC,LL,1,0,76)                                   TAX24910
          CALL PLOT(0.,-3.0,-3)                                              TAX24920
          CALL AXIS(-1.0,0.,15HELEVATION (IN.),15,10.0,90.0,PROF(NN+1),      TAX24930
         1PROF(NN+2))                                                        TAX24940
          CALL PLOT(0.,0.,-3)                                                TAX24950
          XPROF=.25*ABS(PROF(NN+1))/PROF(NN+2)                               TAX24960
          CALL SYMBOL (2.,XPROF,.14,15HNOSE GEAR TRACK,0.,15)                TAX24970
          CALL LINE(TIME,PROF,NN,1,0,74)                                     TAX24980
          XSTOP=XLONG+5.                                                     TAX24990
          CALL PLOT (XSTOP,0.,-3)                                            TAX25000
          WRITE(6,290)                                                       TAX25010
          CALL PLOTE                                                         TAX25020
     295  STOP                                                               TAX25030
     290  FORMAT(*5*)                                                        TAX25040
          END                                                                TAX25050
```

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SUBROUTINE TAYLOR     74/74    OPT=1                    FTN 4.5+R486       05/25/76  10.27.28       PAGE    1

          SUBROUTINE TAYLOR(T,TD,TDD)                                             TAY 0010
          COMMON/FLEX1/SIMAIN(15),SINOSE(15),SIGG(15),SITAIL(15) SIPS(15)        TAY 0020
          COMMON/FLEX2/NFM,GM(15),OMEGA(15),OMEGAA(15),GMA(15)                   TAY 0030
          COMMON/FLEX3/Q(15),QD(15),QDD(15)                                      TAY 0040
          COMMON/FLEX4/QA(15),QDA(15),QDDA(15),NAFM,SILEFT(15),SIRIGHT(15)       TAY 0050
          COMMON/X1/W,WM,WN,MCG,MM,MN,A,B,MMI ,MMIR                              TAY 0060
          COMMON/X2/PAIM,VOM,ASM,AMM,QSM                                         TAY 0070
          COMMON/X3/PAIN,VON,AAN,ANN,QAN                                         TAY 0080
          COMMON/X4/SYM,SXN,SLM,SLN,TSM ,TSN                                     TAY 0090
          COMMON/X5/CL,CD,AREA,THRUST                                            TAY 0100
          COMMON/X6/Z,REACTM,REACTN,DT,NTRUN,SPEED                               TAY 0110
          COMMON/X7/AM,BM,CM,DM,AN,BN,CN,DN,AMR,BMR,CMR,DMR                      TAY 0120
          COMMON/X8/STROKM(20),PINOM(20),STROKN(20),PINON(20),NSCM,NSCN          TAY 0130
          COMMON/X9/FSM,FSN,FTM,FTN,XMAIN,XNOSE,VELM,VELN                        TAY 0140
           COMMON/X99/FSML,FSMR,FTML,FTMR,XMAINL,XMAINR,VELML,VELMR,WS           TAY 0150
          COMMON/X10/ZPM,ZPN,ZPML,ZPMR                                           TAY 0160
          COMMON/X20/COML,SSML,AOML                                              TAY 0170
          DIMENSION T(12), TD(12), TDD(12)                                       TAY 0180
          REAL MCG,MM,MN,MMI,MMIR                                                TAY 0190
    1     Z=Z+TD(11)*DT+TDD(11)*DT**2/2.                                         TAY 0200
  120     ZPML=AML+BML*Z+CML*Z**2+DML*Z**3                                       TAY 0210
           ZPMR=AMR+BMR*Z+CMR*Z**2+DMR*Z**3                                      TAY 0220
          ZPN=AN+BN*Z+CN*Z**2+DN*Z**3                                            TAY 0230
           QTM=0.                                                                TAY 0240
          QTN=0.                                                                 TAY 0250
          QTDN=0.                                                                TAY 0260
           QTDM=0.                                                               TAY 0270
          QALEFT=0.                                                              TAY 0280
          QARIGHT=0.                                                             TAY 0290
          QDLEFT=0.                                                              TAY 0300
           QDRIGHT=0.                                                            TAY 0310
           DO 130 I=1,NFM                                                        TAY 0320
           QTN=QTN+Q(I)*SINOSE(I)                                                TAY 0330
          QTM=QTM+Q(I)*SIMAIN(I)                                                 TAY 0340
           QTDM=QTDM+QD(I)*SIMAIN(I)                                             TAY 0350
  130      QTDN=QTDN+QD(I)*SINOSE(I)                                             TAY 0360
          DO 131 I=1,NAFM                                                        TAY 0370
           QALEFT=QALEFT+QA(I)*SILEFT(I)                                         TAY 0380
          QARIGHT=QARIGHT+QA(I)*SIRIGHT(I)                                       TAY 0390
          QDLEFT=QDLEFT+QDA(I)*SILEFT(I)                                         TAY 0400
  131     QDRIGHT=QDRIGHT+QDA(I)*SIRIGHT(I)                                      TAY 0410
          XNOSE = (T(2) - B * T(8) - T(5)) +QTN                                  TAY 0420
C   RIGHT ROLL IS POSITIVE                                                       TAY 0430
          XMAINL= (T(2) + A * T(8) - T(6)-WS*T(9))  +QTM+QALEFT                  TAY 0440
          XMAINR= (T(2) + A * T(8) - T(5)+WS*T(9))  +QTM+QARIGHT                 TAY 0450
          VELML= TD(2) + A * TD(8) - TD(6)-WS*TD(9) +QTDM+QDLEFT                 TAY 0460
          VELMR= TD(2) + A * TD(8) - TD(5)+WS*TD(9) +QTDM+QDRIGHT                TAY 0470
          VELN = TD(2) - B * TD(8) - TD(5) +QTDN                                 TAY 0480
          IF(XMAINL.GE.0.) XMAINL=-.1                                            TAY 0490
          IF(XMAINR.GE.0.) XMAINR=-.1                                            TAY 0500
          IF(XNOSE.GE.0.) XNOSE=-.1                                              TAY 0510
          IF(VELML.EQ.0.) VELML=-.1                                              TAY 0520
          IF(VELMR.EQ.0.) VELMR=-.1                                              TAY 0530
          IF(VELN.EQ.0.) VELN=-.1                                                TAY 0540
          XML=ABS(XMAINL)                                                        TAY 0550
          XMR=ABS(XMAINR)                                                        TAY 0560
          XNL=ABS(XNOSE)                                                         TAY 0570
```

```
SUBROUTINE TAYLOR    [illegible]

C   NOSE AND MAIN DAMPING FORCE
[illegible]
C   NOSE AND MAIN STRUT PNEUMATIC FORCES
[illegible]
      RETURN
      END
```

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```
SUBROUTINE IC          74/74    OPT=1                        FTN 4.6+446        05/20/76  13.22.30        PAGE    1

              SUBROUTINE IC(  ZCGI,ZMI,ZNI,THETAI)                                     ICE 0010
              COMMON/FLEX1/SIMAIN(15),SINOSE(15),SIZ3(15),SITAIL(15),SIPS(15)          ICE 0020
              COMMON/FLEX2/NFM,GM(15),OMEGA(15)                                        ICE 0030
              COMMON/FLEX3/Q(15),QD(15),QDD(15)                                        ICE 0040
              COMMON/X1/W,WM,WN,MCG,MM,MN,A,B,MMI,MNIR                                 ICE 0050
              COMMON/X2/PAOM,VOM,AAM,AMM,ASM                                           ICE 0060
              COMMON/X3/PAON,VON,AAN,ANN,ASN                                           ICE 0070
              COMMON/X6/SXM,SYN,SLM,SLN,TSM ,TSN                                       ICE 0080
              COMMON/X9/FSM,FSN,FTM,FTN,XMAIN,XNOSE,VELM,VELN                          ICE 0090
               COMMON/X04/FSML,FSNO,FTML,FTNO,XMAINL,XNOSEO,VELML,VELNO,WT             ICE 0100
*******************************************************************************ICE 0110
        C THIS PROGRAM WILL FIND THE INITIAL CONDITIONS FOR  TAXI                      ICE 0120
              REAL MCG,MM,MN,MMI,MNIR                                                  ICE 0130
        C  FOR SXM MAIN AND SYN NOSE GEAR                                              ICE 0140
        C  ZMI= MAIN GEAR TIRE DEFLECTION IN PERCENT                                   ICE 0150
        C  ZNI= NOSE GEAR TIRE DEFLECTION IN PERCENT DEFLECTION                        ICE 0160
        C  ZCGI= CG DEFLECTION                                                         ICE 0170
        C  THETAI= PITCH ANGLE                                                         ICE 0180
        C  XMAIN=  MAIN LANDING GEAR STATIC STROKE                                      ICE 0190
        C  XNOSE=  NOSE GEAR STATIC STROKE                                             ICE 0200
*******************************************************************************ICE 0210
              RM=W/(1.+A/B)                                                            ICE 0220
              RN=W-RM                                                                  ICE 0230
              RM=RM/SXM                                                                ICE 0240
              RN=RN/SYN                                                                ICE 0250
              ZMI=-RM/TSM                                                              ICE 0260
              ZNI=-RN/TSN                                                              ICE 0270
              RSM=RM-WM                                                                ICE 0280
              RSN=RN-WN                                                                ICE 0290
              XNOSE=+PAON*VON/RSN-VON/AAN                                              ICE 0300
              XMAIN=+PAOM*VOM/RSM-VOM/AAM                                              ICE 0310
              THETAI=-(XNOSE+ZNI-(XMAIN+ZMI))/(B+A)                                    ICE 0320
              ZCGI=XMAIN-A*THETAI+ZMI                                                  ICE 0330
               DO 10 I=1,NFM                                                           ICE 0340
               QD(I)=0.                                                                ICE 0350
           10   Q(I)=0.                                                                ICE 0360
              RETURN                                                                   ICE 0370
              END                                                                      ICE 0380
```

```
SUBROUTINE CO -        74/74    OPT=1                    FTN 4.5+R406       05/25/75  10.22.28       PAGE    1

          .OUTINE COEFF (Y,  A,B,C,D)                                COEF0010
          IENSION Y(4)                                               COEF0020
        A=Y(2)                                                       COEF0030
        B=Y(1)                                                       COEF0040
        C=(96.*Y(1)+56.*Y(2)-64.*Y(3)+4.*Y(4))/(-128.)               COEF0050
        D=(-16.*Y(1)-12.*Y(2)+15.*Y(3)-4.*Y(4))/(-128.)              COEF0060
        RETURN                                                       COEF0070
        END                                                          COEF0080
```

```
SUBROUTINE TLOOK       74/74    OPT=1                    FTN 4.5+R406       05/25/76  10.22.28       PAGE    1

          SUBROUTINE TLOOK (X,SLOPE,YCEPT,S,P,N)                     TL  0010
          DIMENSION S(30),P(30)                                      TL  0020
C                                                                    TL  0030
C         THIS IS A 2 DIMENSIONAL TABLE LOOK UP ROUTINE              TL  0040
C         WITH LINEAR INTERPOLATION                                  TL  0050
C                                                                    TL  0060
C     X  IS THE CURRENT VALUE OF STROKE                              TL  0070
C     SLOPE AND YCEPT ARE CALCULATED AND RETURNED                    TL  0080
C     S AND P  MAKE UP THE TABLE                                     TL  0090
C     N IS THE NUMBER OF VALUES IN THE TABLE                         TL  0100
          DO 1 I=1,N                                                 TL  0110
          IF (X.GE.S(I).AND.X.LT.S(I+1))GO TO 2                      TL  0120
  1        CONTINUE                                                  TL  0130
  2       SLOPE=(P(I+1)-P(I))/(S(I+1)-S(I)+.01)                      TL  0140
          YCEPT=P(I)-SLOPE*S(I)                                      TL  0150
          RETURN                                                     TL  0160
          END                                                        TL  0170
```

APPENDIX C
LISTING OF AIRPLANE DATA

- Boeing 727-100
- McDonnell Douglas C-9A
- AMST

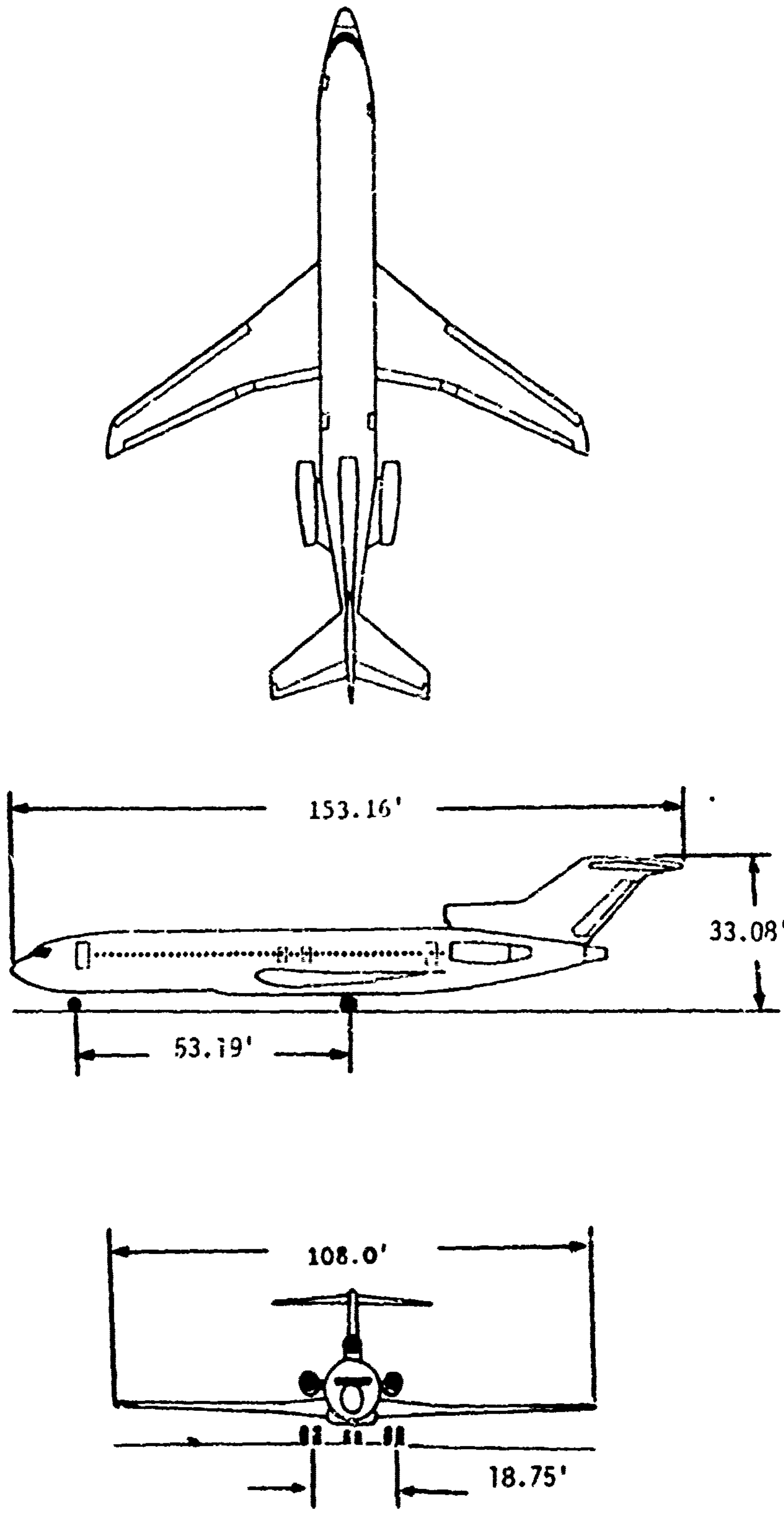

Figure C-1. Three View of Boeing 727-100

***************** INPUT DATA *****************

********* GENERAL AIRCRAFT DATA *********

BOEING 727-100 166200 POUNDS

W= 166200.0	WM= 1303.33	WN= 695.0	A= 70.670	B= 567.703	MMI= 33453300.
SFM= 2.0	SFN= 1.0	SLM= 112.0	SLN= 134.0	PSARM= 645.9	TAILDM= 211.1
AAM= 53.26	AMM= 43.93	PADM= 295.13	VOM= 732.90	OAM= 1.77	TSM = 22740.00
AAN= 19.03	AMN= 24.13	PADN= 253.00	VON= 223.90	OAN= .95	TSN = 8594.00
CL= .912	CD= .104	AREA= 1560.00	SPEED= 50.0	THRUST= 19330.	TAKOFF= 252.00

STRUT NOSE	PIN DIAMETER
2.725	.974
7.485	.976
10.975	1.043
11.420	1.043
11.920	1.080
12.620	1.392

STROKE MAIN	PIN DIAMETER
7.330	1.650
10.022	1.333
12.790	1.393
14.900	1.403

MODE	SIPS	SINOSE	SICG	SIMAIN	SITAIL	OMEGA	GEN. MASS
1	-.23	-.23	-.32	-.03	-.04	14.08	6.0
2	.29	.22	-.08	-.29	-.06	22.97	7.0
3	-.17	-.34	.02	.00	-.04	38.35	2.7
4	-.23	-.15	.11	.09	.02	44.56	13.4
5	.32	.21	-.31	-.31	-.02	49.13	3.9
6	.21	.14	.25	.33	.09	59.66	5.3
7	-.15	-.79	-.14	-.34	.03	75.56	3.6
8	.33	.14	-.12	-.10	-.04	82.63	173.9
9	.80	.13	-.35	-.45	-.13	87.55	25.1
10	-.35	-.23	-.36	-.77	-.16	9[illegible].74	11.5

********* INTIAL CONDITIONS ************

ZMI= -[illegible].113 PHI= -1.479 THETAI= -.005792 ZCGI= -13.573

YMAIN= -13.840 YNOSE= -5.423 [illegible]JCTN= -16143. REACTN= -179851.

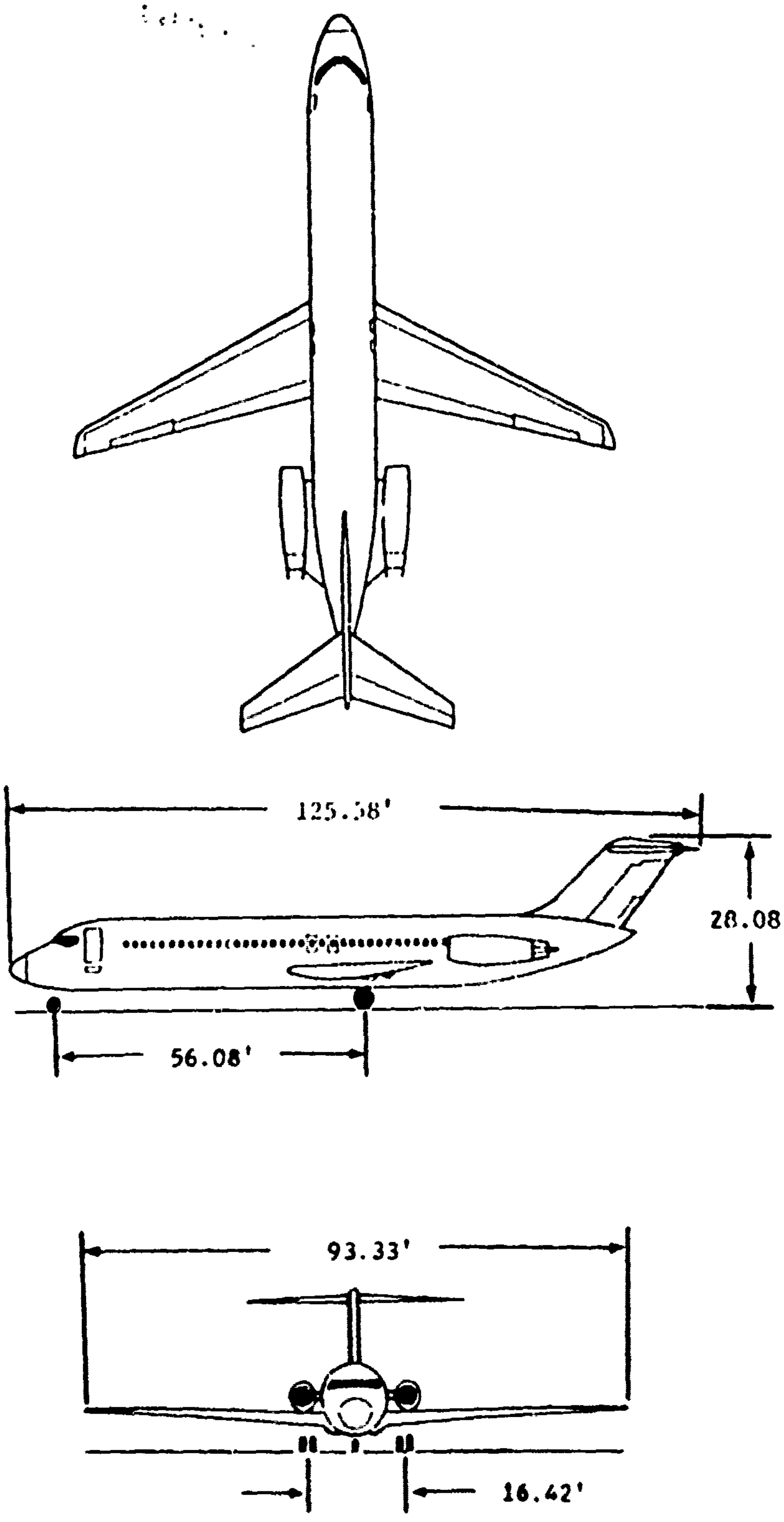

Figure C-2. Three View of McDonnell-Douglas C-9A

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```
**************** INPUT DATA ****************

********* GENERAL AIRCRAFT DATA *********

G=A [illegible]

  WO= [illegible]     WF= 537.15     WW= 153.03     A= 51.60     S= [illegible]     WS= 96.666     WWI= 26868360.
  WWIN= [illegible]

  SAN= [illegible]    SCN= [illegible]    SLM= 65.5    SLN= 47.5    PSANM= [illegible]    TAILRN= 318.5
  AAN= 31.61     ANP= 16.5[illegible]    MAGP= 22[illegible]    VJM= 368.[illegible]    OAM= .5[illegible]    TSN = 23428.57
  [illegible]= [illegible]    ANM= [illegible]    MAGA= 12[illegible]    ZOM= 128.19    OAM= .46    TSN = 8632.48
  CL= [illegible]    CC= [illegible]    ANLA= [illegible]    SP D= 53.3    THRUST= 29[illegible]    TAKOFF= 285.56

STROKE NOS.   PIN DIAMETER
   [illegible]     .28[illegible]
   [illegible]     .[illegible]39
   7.[illegible]     .[illegible]
   12.[illegible]     .713
   15.[illegible]     .72[illegible]

STROKE PAIN   PIN DIAMETER
   [illegible]     [illegible]
   [illegible]     .[illegible]5
   [illegible]     .[illegible]
   11.[illegible]     .713
   17.[illegible]     .[illegible]
```

MODE	SIPS	SINOS	[illegible]	[illegible]	[illegible]	[illegible]	GEN. MASS
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MODE	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]

********* INITIAL CONDITIONS ************

ZMI= [illegible] ZNI= [illegible] THETAI= [illegible] ZCGI= [illegible]

AMAIN= [illegible] ANGLE= [illegible] [illegible] [illegible] [illegible] [illegible]

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```
                                   **************** INPUT DATA ****************

********* GENERAL AIRCRAFT DATA *********

 AMST   150000 POUNDS

  W=  150000.0     WW=   3172.33     WV=    438.22     A=    53.500     T=   427.50     W=   113.333     WMI=   25950000.

  WWJM=   15523330.

  SWM=     2.0     SMN=     1.1     SLM=    18.5     SLN=   172.4     PSAPM=  934.2     TAILAM=  159.2

  AAM=   70.89     AMN=   59.41     PAOM=    93.44     VCM= 1082.00     CAM=    2.72     TSM =  3.000.01

  AAN=   23.75     ANN=   14.07     PAON=   147.33     VON=   754.00     CAN=     .54     TSN =  11443.3.

  CL=    2.650     CD=     .553     AREA= 1740.00     SPEED=    2..     THRUST= 6.3..     TAKEFF=   159.20

 STROKE NOSE   PIN DIAMETER

      0.000         .475
      4.700         .355
      6.000         .543
     11.390         .422
     16.090         .755

 STROKE MAIN   PIN DIAMETER

      0.000        1.300
      2.000        1.70[illegible]
      5.300        1.200
      6.000        1.30[illegible]
     10.000        1.403
     14.000        1.553
     19.000        1.463
     22.000        1.560
     25.000        1.703
     29.000        1.[illegible]03
     99.[illegible]     1.603
```

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MODE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	-.12	-.11	[illegible]	[illegible]	[illegible]	11.71	[illegible]
2	-.02	-.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	.02	.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	-.76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	-.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	.29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	-.36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	-.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	.03	.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	-.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

********** INITIAL CONDITIONS ************

[illegible]

[illegible]

APPENDIX D
LISTING OF RUNWAY PROFILES

1. Figure D-1 - Washington National Runway 36-Left, Center, and Right hand profiles.
2. Profile data listing of the 1-cos dip used in these simulations. All three lines of profile were identical except that they occur at different times corresponding to the gear locations.

Figure D-1. Washington National Runway 36 with Linear Trend Removed

BIBLIOGRAPHY

Butterworth, C. K., and Boozer, D. E., Jr., C-141A Computer Code for Runway Roughness Studies, AFWL-TR-70-71, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, August 1970.

Chance Vought Corporation, A Rational Method for Predicting Alighting Gear Dynamic Loads, ASD-TDR-62-555, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, December 1963.

Cook, Robert F., Use of Discrete Runway Profile Elevation Data in Determining the Dynamic Response of Vehicles, TM-68-3-FDDS, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, May 1968.

Crenshaw, B. M., and Butterworth, C. K., Lockheed Georgia Company, Aircraft Landing Gear Dynamic Loads from Operation on Clay and Sandy Soil, AFFDL-TR-69-51, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, February 1971.

NACA TN 2477, Investigation of the Air-Compression Process During Drop Tests of an Oleo-Pneumatic Landing Gear, 1951.

Quade, Delmar A., The Boeing Company, Wichita Division, Location of Rough Areas of Runways for B-52 Aircraft, AFFDL-TR-67-175, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, March 1968.

REFERENCES

1. Goldman, D. E., and von Gierke, H. E., "Effects of Shock and Vibration on Man," Volume III, Chap. 44, Shock and Vibration Handbook (C. M. Harris and C. E. Crede, editors) McGraw Hill Book Co., New York, 1961.

2. Gerardi, A. G., Lohwasser, A. K., Computer Program for the Prediction of Aircraft Response to Runway Roughness, AFWL-TR-73-109, Volume I and II, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, September 1973.

U.S. Government Printing Office 1977 - 757-080/23